# Water Resources Inventory and Assessment

# Parker River National Wildlife Refuge

## Newbury, Massachusetts

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# 1 EXECUTIVE SUMMARY

Water Resources Inventory and Assessments (WRIA) are being developed by a national team of hydrologists within the U.S. Fish and Wildlife Service (Service). The purpose of these assessments is to provide reconnaissance-level information on water resources at National Wildlife Refuges (NWRs) and National Fish Hatcheries. The goal of every WRIA is to provide a basic understanding of the water resources that are important to the facility and assess the potential threats to those resources. Data collected in the WRIAs are being incorporated into a national database so water resources can be evaluated nationally and between regions. Information collected for the WRIAs can be used to support Comprehensive Conservation Plans, Hydro-Geomorphic Assessments, and other habitat management plans.

## 1.1 Findings

1. Average total precipitation for the year in the vicinity of Parker River National Wildlife Refuge is about 41 inches. Precipitation is distributed relatively evenly throughout the year and averages about 3.5 inches/month.

2. Approximately 85% of the acquisition boundary is considered wetlands using the National Wetland Inventory (NWI) classification system. 80% of the refuge's wetland area is classified by NWI as estuarine wetlands and the remaining 5% are freshwater wetlands.

3. Plum Island Sound and the rivers flowing into it are considered water quality limited due to fecal coliform and pathogen contamination.

4. USGS databases identify 2 water quality monitoring sites on, or near, the refuge. However, there are more than 20 additional sites where water quality is monitored by other organizations like the Ipswich River Watershed Association and the Parker River Clean Water Association.

5. USGS databases identify 10 water quantity monitoring sites on, or near, the refuge. However, there are more than 10 additional sites where water quantity is monitored by other organizations like the Ipswich River Watershed Association and the Plum Island Long Term Ecological Research Station.

6. Massachusetts recently completed the Sustainable Water Management Initiative (SMWI). The goal of the SWMI is to quantify the volume of water available for human use in Massachusetts' watersheds while still leaving enough water in rivers and streams to support aquatic habitat and the species that depend on it.

7. Long term climate records near Parker River NWR indicate air temperature has increased approximately 3 degrees Fahrenheit (°F) since 1895.

## 1.2 Recommendations/Further Actions

More than 75% of the Parker River NWR acquisition boundary is estuarine marsh and deepwater habitat. The loss of this habitat due to sea level rise is, of course, the most obvious long-term threat to the refuge. The primary threats to water resources at Parker River National Wildlife Refuge are associated with sea level rise and water quality conditions in Plum Island Sound.

### *1.2.1 Water Level Monitoring near Interdunal Swales*

The refuge is already monitoring water levels and surface elevations in Plum Island Sound salt marshes. These efforts should continue and can build a long-term record that tracks changes to refuge habitat due to sea level rise. However, it appears less emphasis has been placed on monitoring water level conditions in the freshwater lens that supports Plum Island's interdunal swales. Although these wetlands are a small percentage of the total wetland acreage on the refuge, they are ecologically important freshwater wetland communities. Recent studies (Masterson et al 2013) suggest freshwater lens aquifers in barrier islands can be particularly sensitive to sea level rise. The refuge should consider adding one or two shallow groundwater wells with continuous water level recorders in the dune field adjacent to interdunal swales. These data will complement other water level monitoring in refuge salt marshes and build a long-term dataset that quantifies the impacts of sea level rise on refuge freshwater resources.

### *1.2.2 Continue to support watershed restoration and salt marsh restoration efforts*

Parker River NWR is fortunate to be located in a watershed with multiple partner organizations who are dedicated to improving the overall quality of the Sound and the rivers that flow into it. Recent observations of increased inundation of high marsh and the associated conversion of high marsh to low marsh habitat, suggests salt marsh loss due to sea level rise is already occurring. As a major land owner of salt marsh in Plum Island Sound, the refuge is well situated to pilot new techniques for restoring natural hydrologic conditions to improve the resiliency of the Sound's salt marshes

Recommend the refuge continue to support restoration projects that mitigate the impacts of grid ditching and tidal flow restrictions in Plum Island Sound salt marshes. In addition, recommend the refuge continue supporting efforts to reduce stormwater runoff and improve water quality in the rivers flowing into the Sound. The Parker River watershed is particularly important because water quality conditions in this river have the most impact on the portion of the Sound within the refuge boundary. Restoration activities that reduce stormwater runoff and restore rivers' natural flow regimes can benefit the Sound by reducing water quality impairments, increasing summertime freshwater inputs, and increasing the sediment supply to the Sound.

# 2 INTRODUCTION

This Water Resource Inventory and Assessment (WRIA) Summary Report for Parker River National Wildlife Refuge (NWR) describes current hydrologic information, provides an assessment of water resource issues of concerns, identifies water resource needs, and makes recommendations regarding refuge water resources. The information contained within this report and supporting documents will be entered into the national WRIA database.

Together, the national WRIA database and summary reports are designed to provide a reconnaissance-level inventory and assessment of water resources on National Wildlife Refuges and National Fish Hatcheries. A national team of U.S. Fish and Wildlife Service (Service) Water Resource staff, Environmental Contaminants Biologists, and other Service employees developed the standardized content of the national WRIA database and summary reports.

The long-term goal of the National Wildlife Refuge System (NWRS) WRIA effort is to provide up-to-date data on a facility's water quantity and quality in order to protect adequate supplies of clean and fresh water. An accurate water resources inventory is essential to prioritize issues and tasks, and to take prescriptive actions that are consistent with the established purposes of the refuge. Reconnaissance-level water resource assessments evaluate water rights, water quantity, known water quality issues, water management, potential water acquisitions, threats to water supplies, and other water resource issues for each field station.

WRIAs are recognized as an important part of the NWRS Inventory and Monitoring (I&M) Program and are outlined in the I&M Draft Operational Blueprint as Task 2a. Hydrologic and water resource information compiled during the WRIA process will help facilitate the development of other key documents for each refuge including Hydrogeomorphic Analyses (HGM) and Comprehensive Conservation Plans (CCP).

## 2.1 Parker River NWR WRIA

This WRIA Summary Report for Parker River NWR incorporates hydrologic information compiled between May 2012 and July 2013. The report is intended to be a reference for ongoing water resource management and strategy development. However, the document is not meant to be exhaustive or a historical summary of activities on Parker River NWR. This WRIA was developed in conjunction with refuge staff under a contract with Atkins North America, Inc. in 2012 and 2013.

# 3 FACILITY INFORMATION

**Parker River National Wildlife Refuge**

Parker River National Wildlife Refuge (NWR) (referred to as the refuge) is located in eastern Essex County, Massachusetts; along the Atlantic coast in the towns of Newbury, Rowley and Ipswich (Figure 1). The refuge was established in 1941 to provide feeding, resting and nesting habitat for migratory birds. Authority for managing and acquiring the land for the National Wildlife Refuge System falls under the Migratory Bird Conservation Act of 1929, Fish and Wildlife Act of 1956, and the Emergency Wetlands Resources Act of 1986. The refuge is located on the Atlantic Flyway and is an important stopover for waterfowl, shorebirds, and songbirds during pre- and postbreeding migratory periods. The refuge's beaches provide important breeding and migrating habitat for the threatened piping plover (USFWS 2008).

The acquisition boundary of the refuge encompasses 6,388 acres[1]; 4,662 acres (73%) includes land acquired by the Service, the remaining 1,726 acres (27%) is entirely in Plum Island Sound. The refuge is composed of diverse upland and wetland habitats including sandy beach, dune, maritime shrubs and forests, salt marsh, man-made impoundments, grassland habitats, glacial upland habitats and deepwater estuarine habitat. Primary refuge concerns include the impacts of seal level rise on refuge salt marshes, nutrient loading from suburban development in the watershed, and water exports from the Parker and Ipswich rivers for municipal water supplies.

[1] For the purposes of this report, all units are expressed in English measures, unless citing information from a primary source where the native data are presented in metric units. In those cases, the English unit conversions are also provided.

# 4 NATURAL SETTING

## 4.1 Topography, Landforms, and Hydrologic Units

Most of the land owned by the refuge is on Plum Island, an island of dune fields and salt marshes bordered by Plum Island Sound to the west and the Atlantic Ocean to the east. The refuge is in the Seaboard Lowland section of the New England physiographic province, which has mostly gently rolling terrain with isolated mountains and steep hills. Elevations in the Parker River watershed range from 300 ft in the western headwaters to sea level at the river's mouth where it enters Plum Island Sound (Massachusetts EOEA 2005). The eastern portion of the Parker River watershed is composed of extensive salt marshes interlaced with tidal creeks and streams. Topography on the refuge ranges from 0 to 64 feet above sea level (Figure 2) (Gomez and Sullivan 2003).

The U.S. Geological Survey (USGS) has developed a national dataset of hydrologic units. Hydrologic units are based on watershed boundaries and are assigned Hydrologic Unit Codes (HUC). Two-digit HUCs are applied to the largest areas, which are defined as regions. Regions are subdivided into 4-digit subregions, which are then further subdivided down to smaller areas. For the purposes of this WRIA, the 8-digit (subbasin) and 10-digit HUCs (watershed) hydrologic units contributing to Parker River NWR will be referenced (Figure 1). These HUCs are important because they are used by many federal and state agencies to track water monitoring and regulatory activities.

Parker River NWR is part of two 8-digit hydrologic subbasins: the Charles (01090001) and Merrimack (01070002). At the 10-digit watershed scale, Parker River NWR is part of the Ipswich (0109000102), Plum Island Sound/Frontal Atlantic (0109000101), and Powwow River-Merrimack River (0107000614) watersheds (Figure 1, Figure 5). Of these, the WRIA focuses on the Plum Island Sound/Frontal Atlantic watershed because this hydrologic unit encompasses the entirety of the Parker River watershed.

For state planning purposes, the 10-digit hydrologic units for the Parker and Ipswich Rivers (Figure 1) are identified as Massachusetts state planning basins 16 and 17, respectively.

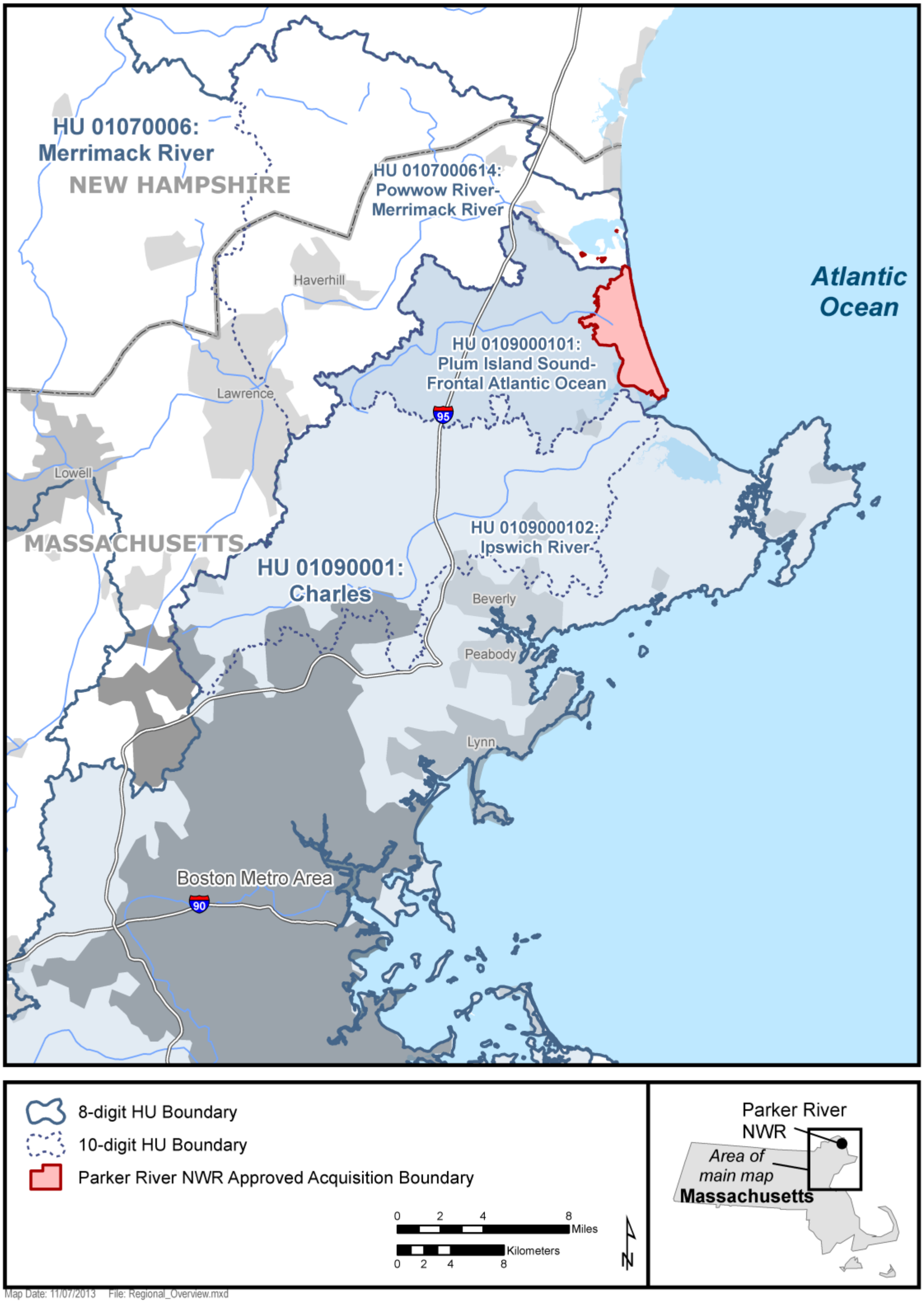



Figure 1. Regional overview map showing Parker River NWR location in relation to Hydrologic Units.

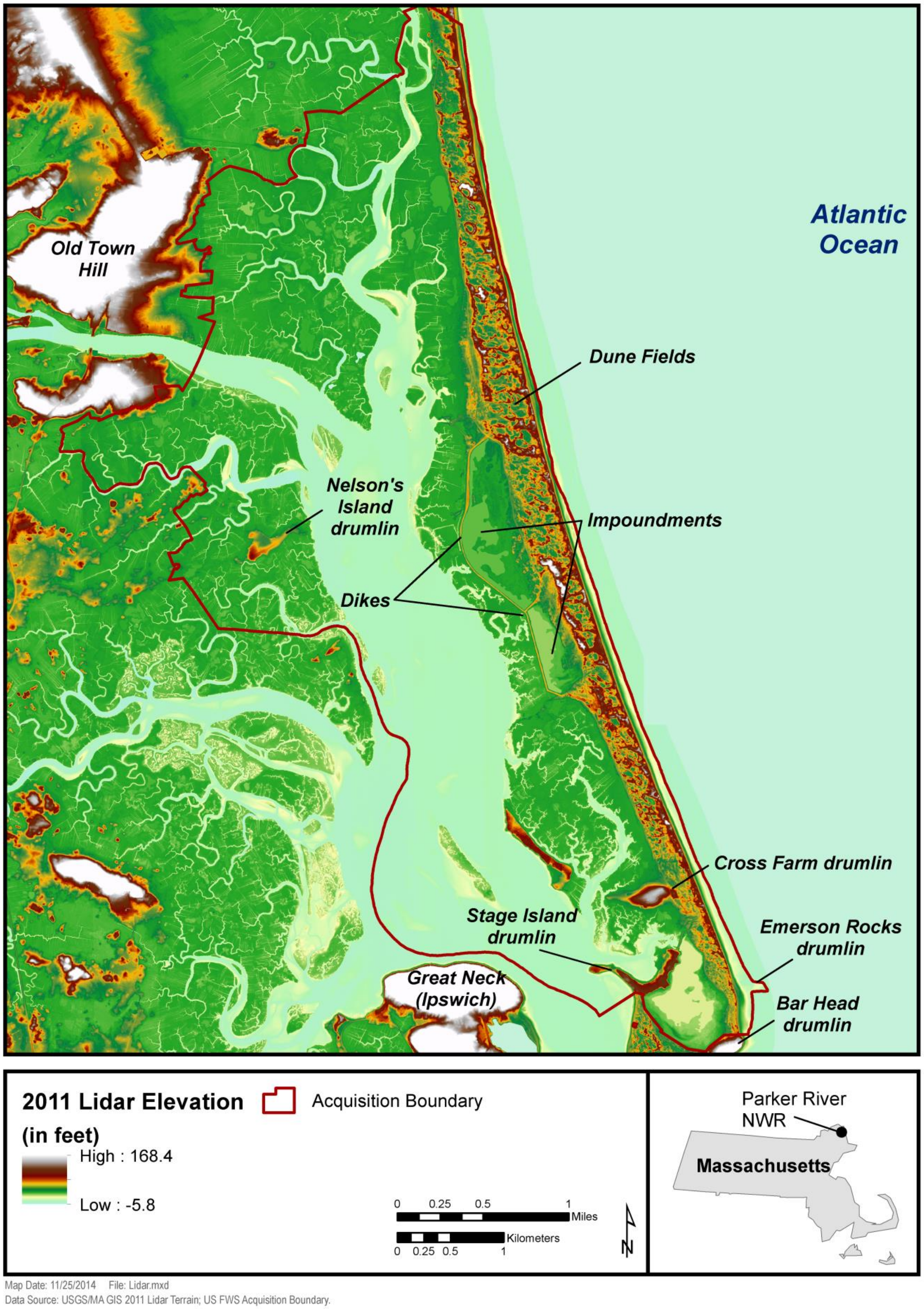
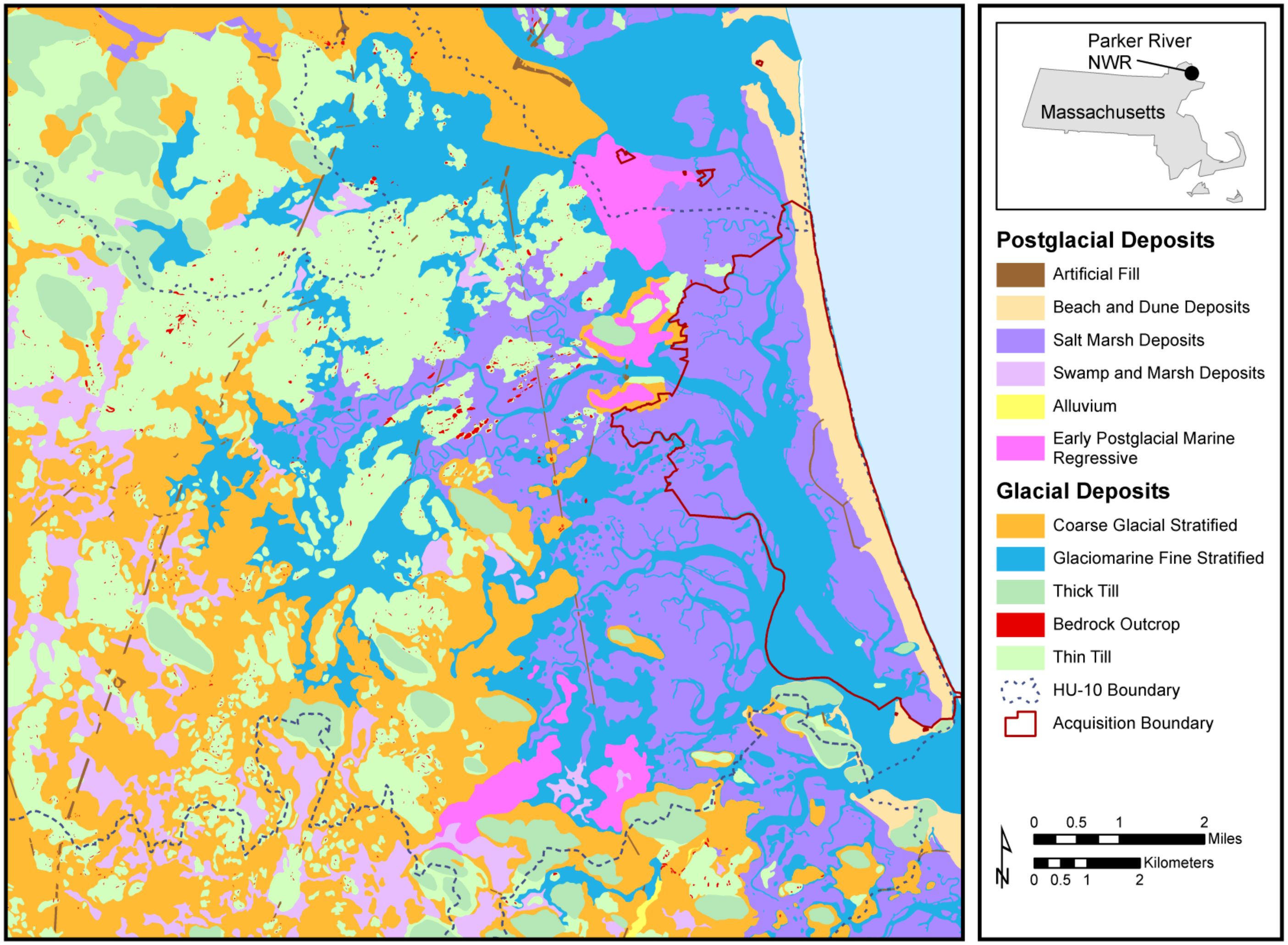



Figure 2. 2011 LiDAR ground surface elevation in and around Parker River NWR.

## 4.2 Geology

The geology of the Parker River watershed has been shaped by past glaciations (Figure 3). A recent study of Plum Island evolution found that the barrier island overlies glacial tills from the Wisconsinan and Illinoian glacial periods, as well as late Pleistocene glaciomarine clay (Hein et al 2012). The last glacial retreat (Wisconsinan period) ended approximately 10,000 years ago, and as the glacier melted, glacial till and bedrock became exposed. Glacial debris and sediments were transported by rapidly melting ice and over time were reworked and formed into the existing coastal features. More recent (Holocene-age) sediment began to accumulate around 7,000 to 8,000 years ago from erosion of the Parker River channel. Silt and clay were deposited in lowlands and later covered by tidal marsh deposits (Buchsbaum et al 2002). The present day barrier island and its tidal marshes are believed to have originated approximately 6,000 years ago from the formation of a sandspit (Buchsbaum et al 2002). Formation of the sandspit is thought to be driven by southerly longshore currents that carry sediment from the Merrimack River. These same currents dominate present-day sediment supply to some portions of Plum Island (Hein et al 2012).

The surficial geology of the refuge consists of glacial outwash (stratified sand and gravel deposits), marine and estuarine deposits (sands, silt and clay), floodplain alluvium, swamp deposits (organic muck), glacial till, and bedrock outcrops. Overlying glacial deposits are more recent deposits of beach and dune sand (MCZM 2000, Gomez and Sullivan 2003). Marine silts and clays positioned relatively high on the landscape were uplifted above present sea level when the land rebounded after glacial retreat (MCZM 2000). Along the Parker River-Plum Island Sound Estuary there are several thick deposits of glacial till overlying bedrock in Great Neck, the drumlins at Castle Hill, Old Town Hill and at the southern end of Plum Island (i.e., Sandy Point, Bar Head, Emerson Rocks) (Buchsbaum et al 2000, Hein et al 2012). Some of these features are clearly visible in the LiDAR elevation map (Figure 2).




Map Date: 11/19/2013 File: Geology.mxd Data Source: MA 1:24,000 Surficial Geology, ESRI Map Service.

Figure 3. Surficial geology of the region surrounding Parker River NWR.

### 4.3 Soils

Soil types in the lower section of the Parker River include Ipswich and Westbrook mucky peats (poorly drained, inundated daily), Agawam fine sandy loam (well drained, moderate to rapid permeability), Maybid silt loam (deep, poorly drained and slow permeability) and Canton extremely fine silty loam (moderately rapid permeability) (Buchsbaum et al 2002).

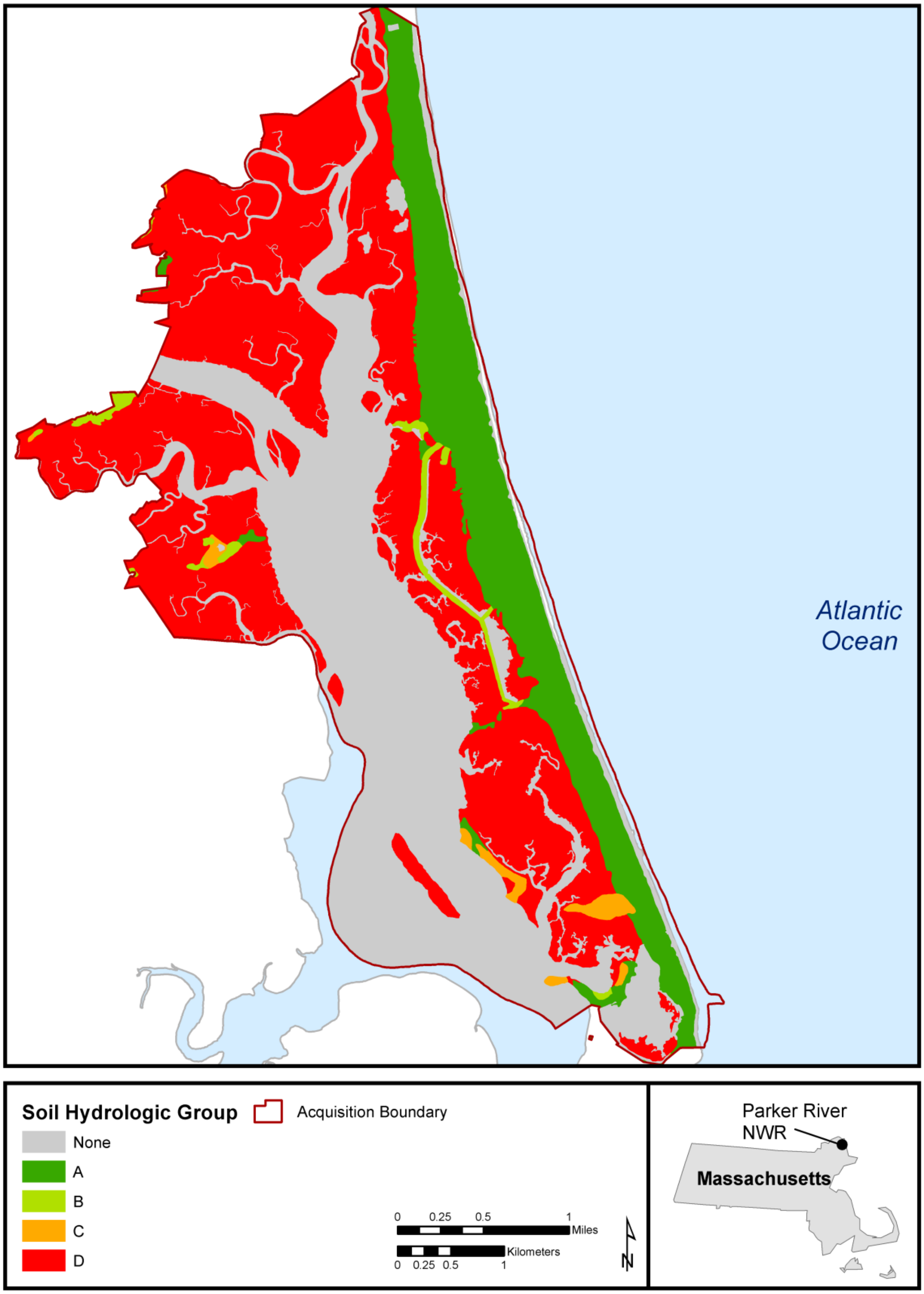
The Natural Resources Conservation Service (NRCS) assigns a hydrologic group to each map unit as an indicator of the runoff potential for the soil unit. There are four groups, ranging from A to D. Hydrologic group A has the highest infiltration rate, meaning rain falling on these soils will infiltrate into the subsurface quickly and surface water runoff rates will be low. Precipitation falling on A type soils is more likely to recharge underlying groundwater aquifers. Hydrologic group D has the lowest infiltration rate, meaning rain falling on these soils is more likely to pond on the surface and run off the land quickly. Very little groundwater recharge occurs in areas with D type soils. If a soil is assigned to a dual hydrologic group, the first letter is for drained areas and the second letter is for undrained areas.

The peaty salt marsh and glacial till soils that make up the majority of the Parker River NWR acquisition boundary (44%) fall into hydrologic groups C and D, which are characterized by slow infiltration and high runoff potential (Table 1, Figure 4). Soils with the highest capacity for infiltration (A and B) occur in the beaches and dune fields of Plum Island (Figure 4). In the Parker River watershed, more than half of soils fall within groups C and D (Table 1). In general, soils with higher infiltration and lower runoff potential occur in the western portion of the Plum Island Sound-Frontal Atlantic watershed.

Nearly 40% of soils in the Parker River NWR acquisition boundary have not been assigned a hydrologic group (as compared with 11% in the greater watershed). These unclassified areas appear to correspond to areas of open water and areas of modified land, such as the dikes built around impoundments on the refuge.

Table 1. Soil hydrologic groups within the Plum Island Sound-Frontal Atlantic watershed and on Parker River NWR.

| Hydrologic Group | Acres in Watershed | % of Watershed | Acres on Refuge | % of Refuge |
|---|---|---|---|---|
| None | 5852.3 | 10.5 | 2471.4 | 39.4 |
| A | 6471.0 | 11.6 | 945.8 | 15.1 |
| B | 13530.7 | 24.2 | 83.1 | 1.3 |
| C | 10021.8 | 17.9 | 61.6 | 1.0 |
| C/D | 103.0 | 0.2 | n/a | n/a |
| D | 19943.0 | 35.7 | 2716.8 | 43.3 |
| ***Total*** | ***55921.8*** | ***100.0*** | ***6278.7*** | ***100.0*** |




Map Date: 11/19/2013 File: Soils.mxd
Data Source: NRCS SSURGO Soils; US FWS Acquisition Boundary.

Figure 4. Soil hydrologic groups within the boundaries of Parker River NWR.

## 4.4 Land Use

The National Land Cover Database (NLCD) serves as the definitive Landsat-based, 30-meter resolution, land cover database for the Nation. NLCD is created by the Multi-Resolution Land Characterization (MRLC) consortium, a group of federal agencies who coordinate and generate consistent and relevant land cover information at the national scale for a wide variety of environmental, land management, and modeling applications. For the purposes of this WRIA, the NLCD data is presented to review land use characterizations for the refuge and the surrounding watershed. The most recently available (2001) NLCD land cover classifications have been lumped into more generalized classes (Table 2, Figure 5). Within the refuge boundary, the dominant land use types consist of open water and wetlands. The percentage of area in these classes is greater on the refuge than in the surrounding Parker River watershed area; however, wetlands make up the second most dominant land cover class in the watershed (Table 2).

Table 2. 2001 National Land Cover Dataset land use on Parker River NWR and within the Plum Island-Frontal Atlantic watershed. Descriptions of lumped classifications appear below.

| Land Cover Class | Acres on Refuge | % of Refuge | % of Watershed |
|---|---|---|---|
| Agriculture[1] | 10.7 | 0.2 | 7.8 |
| Barren Land | 614.0 | 9.8 | 1.4 |
| Developed[2] | 160.8 | 2.6 | 16.2 |
| Forested[3] | 34.9 | 0.6 | 35.1 |
| Grassland/Herbaceous | 243.5 | 3.9 | 1.1 |
| Open Water | 2400.5 | 38.3 | 7.9 |
| Scrub/Shrub | 0.0 | 0.0 | 0.3 |
| Wetlands[4] | 2805.5 | 44.7 | 30.3 |
| ***Total*** | ***6270.0*** | ***100.0*** | ***100.0*** |

1- Includes the NLCD pasture and cultivated crops classes. There is no agricultural activity on the refuge at the time of writing. The identified area is on Nelson Island and probably is a misinterpretation of the satellite imagery.
2- Includes the NLCD developed open space, developed low intensity, developed medium intensity, and developed high intensity classes.
3- Includes the NLCD deciduous forest, evergreen forest, and mixed forest classes.
4- Includes the NLCD woody wetlands and emergent herbaceous wetlands classes.

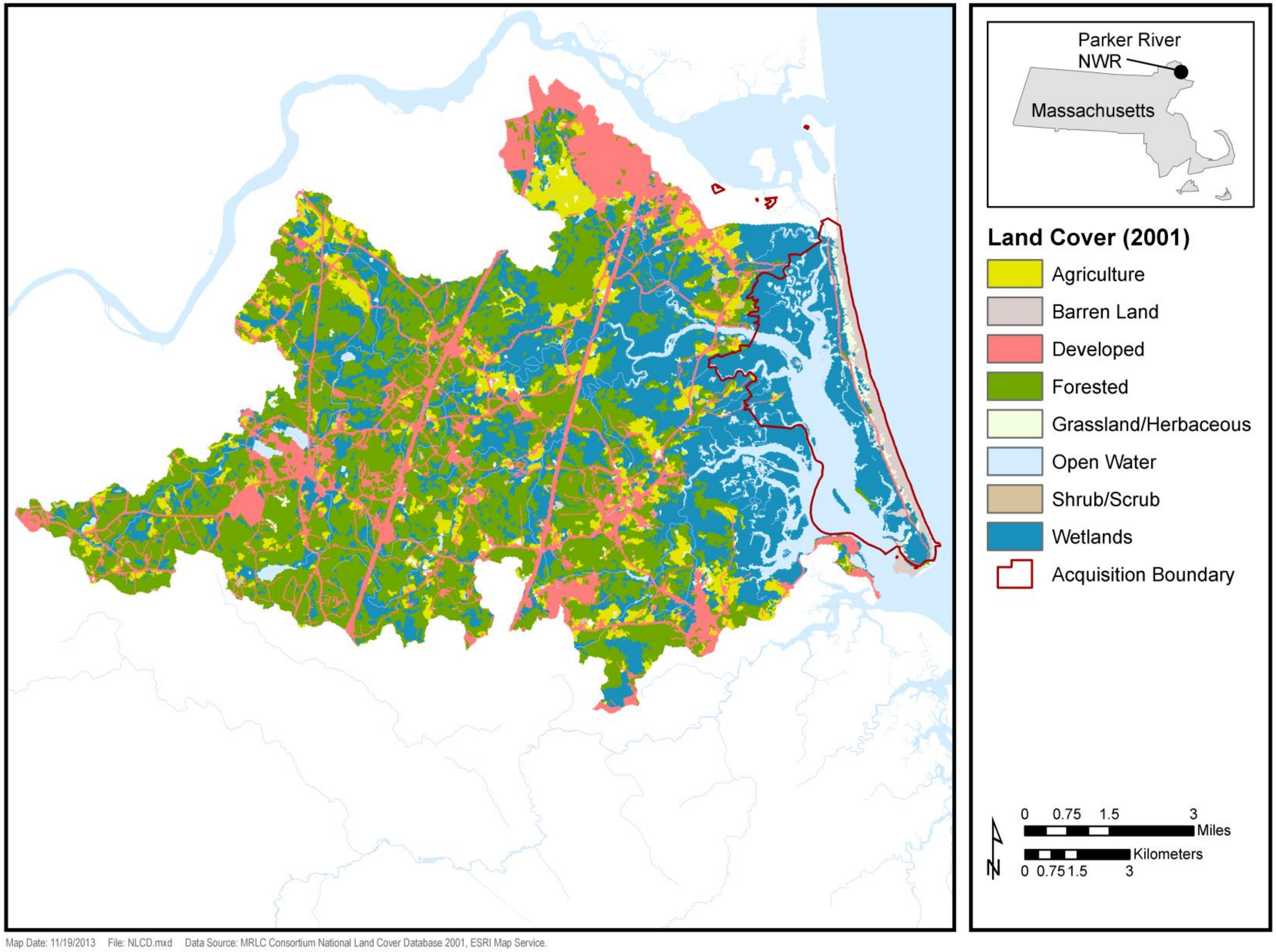



Figure 5. National Land Cover Dataset 2001 Land Cover within the Plum Island Sound-Frontal Atlantic watershed.

## 4.5 Hydro-climatic setting

### *4.5.1 Precipitation Patterns*

The U.S. Department of Agriculture's official climatological data comes from the PRISM (Parameter-elevation Regressions on Independent Slopes Model) climate mapping system, developed by Dr. Christopher Daly, of the PRISM Climate Group at Oregon State University. PRISM is a unique knowledge-based system that uses point measurements of precipitation, temperature, and other climatic factors to produce continuous, digital grid estimates of monthly, yearly, and event-based climatic parameters. Data are continuously updated, and can be downloaded for a specified region or by latitude/longitude.

The 1971 – 2000 climatological normals for the refuge indicate average annual precipitation is almost 47 inches, occurring relatively evenly across the seasons. Temperatures range from an average minimum of almost 19°F in January to an average maximum of 81°F in July (Table 3).

Monthly snowfall averages at the Ipswich, MA National Weather Service (NWS) station over the period of record (1926 – 2009) are presented in Table 4, below.

Table 3. PRISM monthly normals (1971 – 2000) for -70.795534, 42.744585 (PRISM Climate Group 2010).

| Month | Precipitation (in) | Max Temperature (F) | Min Temperature (F) |
|---|---|---|---|
| January | 4.25 | 35.82 | 18.81 |
| February | 1.81 | 37.92 | 20.84 |
| March | 4.26 | 45.52 | 28.45 |
| April | 4.28 | 55.4 | 37 |
| May | 3.52 | 65.88 | 46.56 |
| June | 3.65 | 74.7 | 55.9 |
| July | 3.33 | 80.08 | 61.52 |
| August | 3.32 | 78.19 | 60.6 |
| September | 3.86 | 70.39 | 53.08 |
| October | 4.15 | 60.58 | 42.39 |
| November | 4.56 | 50.7 | 34.41 |
| December | 4.2 | 40.68 | 24.62 |
| Total Precipitation | **46.97** | | |
| Average Temperature | | **57.99** | **40.35** |

Table 4. Average monthly snowfall at the National Weather Service station (IPSM3) at Ipswich, MA over the period of record (1926-2009). Downloaded from http://weather-warehouse.com.

| Month | Average Snowfall (in) |
|---|---|
| January | 14.1 |
| February | 14.6 |
| March | 9.6 |
| April | 2.2 |
| May | 0.0 |
| June | 0.0 |
| July | 0.0 |
| August | 0.0 |
| September | 0.0 |
| October | 0.1 |
| November | 2.1 |
| December | 10.7 |
| Total | 53.4 |

### *4.5.2 Streamflow Patterns*

The closest long-term USGS stream gage to Parker River NWR is located on the Parker River at Byfield, MA. The station has a period of record from 1945 to the present. Runoff records at the gage are thought to be representative of runoff patterns in other streams flowing into Plum Island Sound.

Runoff in the Parker River shows a strong snowmelt runoff response, with streamflow peaking in March of the year. Once snow has melted in the watershed, the flow rate drops considerably, eventually reaching the lowest flows of the year in August and September at the end of the growing season (Figure 6). The average annual discharge for the Byfield gage's period of record is 39 cubic feet per second (cfs). However a recent study suggests the average annual flow between 1998 and 2007 is much lower and closer to 17 cfs (Horsley Witten Group, Inc. 2008).

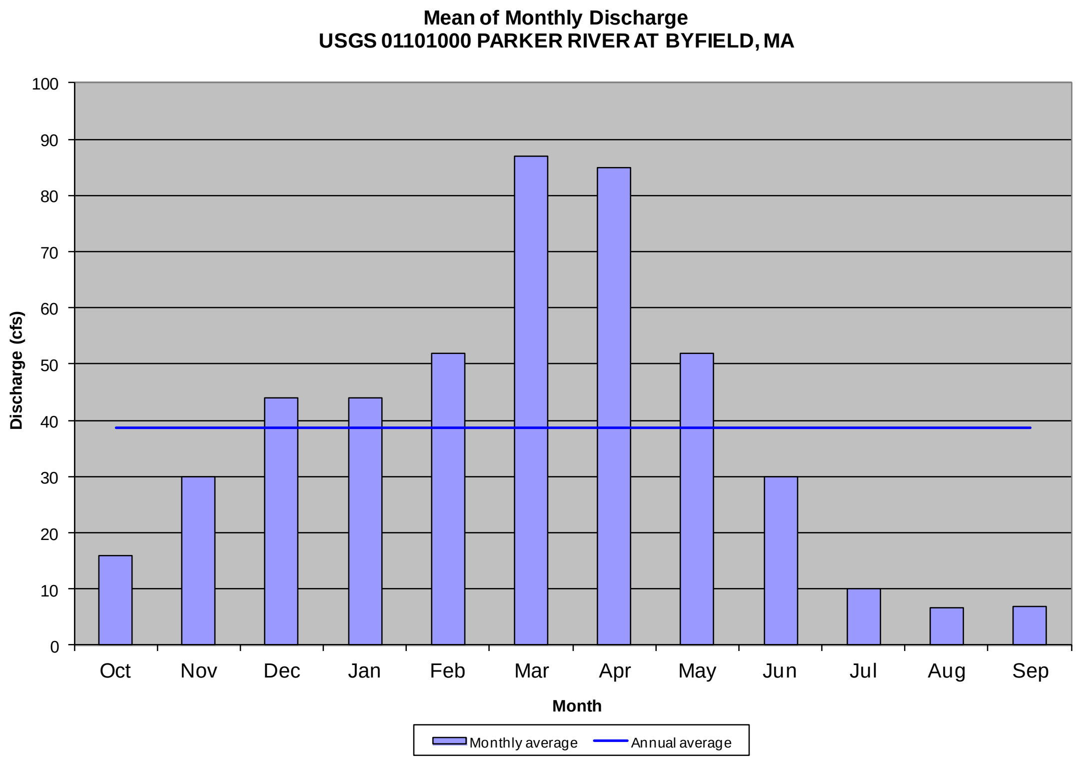



Figure 6. Average monthly discharge from the Parker River at Byfield, MA. From data collected between 1945 – 2011.

# 5 INVENTORY

This section of the WRIA summarizes basic information on a refuge's water resources, water-related infrastructure, water quality, water monitoring, water rights, and climatic trends. Data from this section is incorporated into the national WRIA database. Data on waterbodies from the National Hydrography Dataset (NHD) are presented in Section 5.1. Because of the coarse scale of these data, they are not expected to be a perfect representation of stream and water body locations.

## 5.1 Water Resources

Surface water features include lakes, ponds, springs, impoundments, reservoirs, rivers, streams, and creeks. Groundwater resources include regional and local aquifers that are important to the surface water resources of the refuge. Also included are wetlands identified in National Wetland Inventory maps that cover the refuge area.

### *5.1.1 Rivers / Streams / Creeks*

In the absence of more specific information, the WRIA relies on the USGS 1:24,000 scale NHD flowlines to inventory streams at Parker River NWR (Table 5, Figure 7). The focus of the preliminary analysis is on named NHD features because they tend to be the largest and, theoretically, of most interest to U.S. Fish and Wildlife Service (Service) facilities.

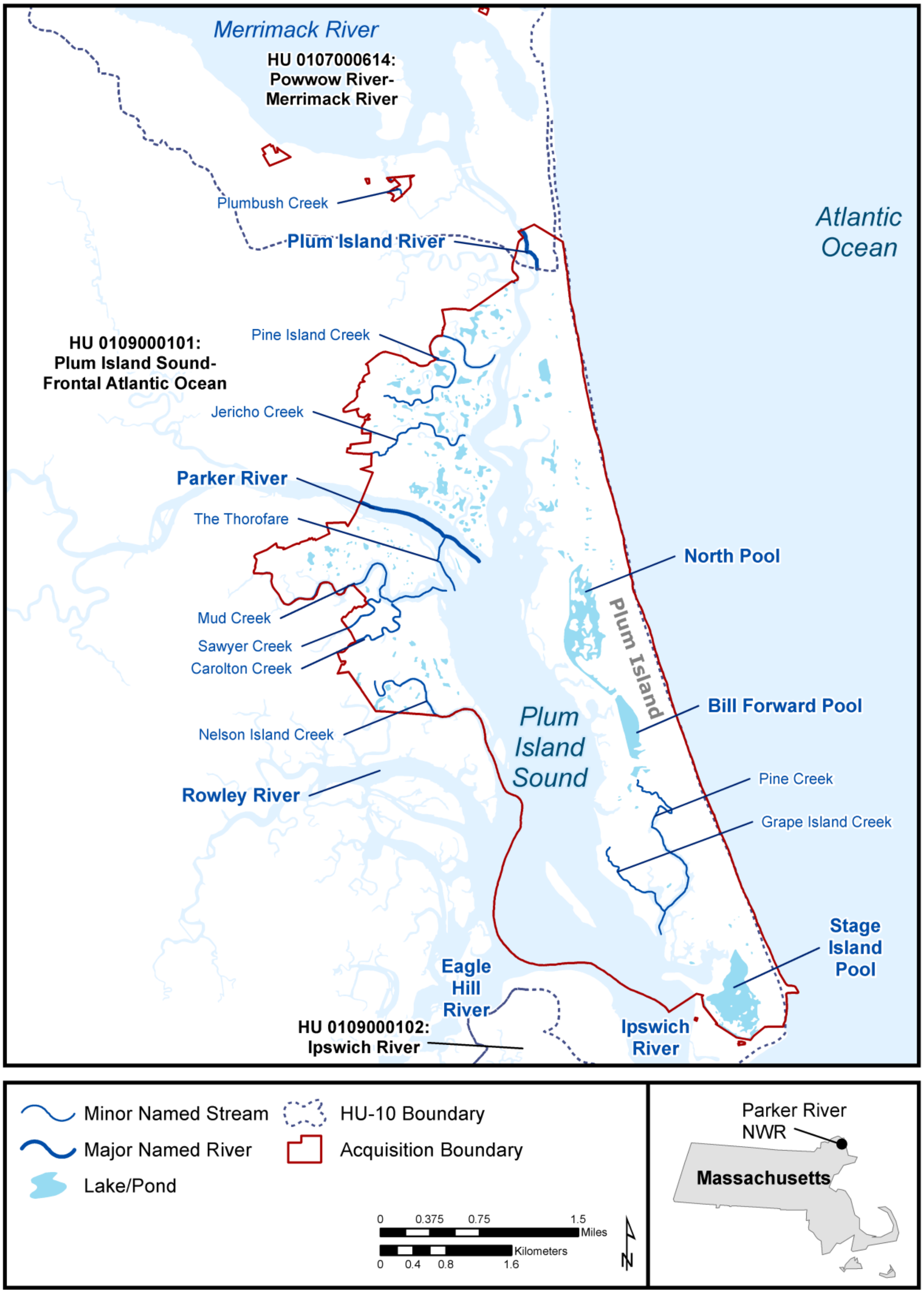
Review of the NHD dataset for Parker River uncovered several challenges and inconsistencies with how tidal channels are defined. After reviewing these data we chose to rely instead on the 1999 Networked Hydro Centerlines dataset of stream and river channels developed by the Massachusetts Office of Geographic Information (MassGIS) to inventory these features at Parker River. The Networked Hydro Centerlines data identifies 108 miles of rivers and tidal creeks within the refuge acquisition boundary (Table 5). Two relatively large tidal channels, Jericho Creek and Pine Island Creek, are not explicitly named in the MassGIS dataset.

Table 5. Named creeks and streams from the MassGIS Networked Hydro Centerlines dataset. Includes features within Parker River NWR's acquisition boundary. Also includes several features named in the National Hydrography Dataset (NHD) flowlines that are not named in Mass GIS (indicated by *).

| Stream Name | Miles Within Acquisition Boundary |
|---|---|
| Unnamed Stream/River | 97.2 |
| Carolton Creek | 0.8 |
| *Jericho Creek | 1.1 |
| Grape Island Creek | 0.8 |
| Mud Creek | 1.7 |
| Nelson Island Creek | 0.7 |
| Parker River | 1.0 |
| Pine Creek | 1.6 |
| *Pine Island Creek | 1.7 |
| Plum Island River | 0.3 |
| Plumbush Creek | 0.1 |
| Sawyer Creek | 0.5 |
| The Thorofare | 0.5 |
| ***Total*** | ***108*** |

### *5.1.2 Lakes and Ponds*

In the absence of more specific information the WRIA relies on the USGS 1:24,000 scale NHD waterbodies to inventory natural lakes and ponds at Parker River NWR. According to the NHD there are 317.5 acres of lakes and ponds within the refuge acquisition boundary. However, this is clearly an overestimate of the natural lake and pond features on the refuge. Of the 317 acres, approximately 174 acres occupy the managed impoundments of Stage Island Pool, North Pool, and Bill Forward Pool. The remaining 159 acres of lakes and ponds are small features that are less than one acre to 8 acres in size. The majority of these small, unnamed features identified by the NHD are thought to correspond to interdunal swales and unmanaged pools and pannes in the salt marsh. As these are small freshwater wetlands and salt marsh features with brackish to saline water they should not be considered lakes or ponds (Nancy Pau, personal communication).




Map Date: 11/08/2013 File: Streams_Waterbodies.mxd
Data Sources: MassGIS Networked Hydro Centerlines; National Hydrography Dataset High Resolution Flowlines and Waterbodies; USGS Watershed Boundaries; ESRI Map Service

Figure 7. Named creeks, streams and waterbodies from 1:25,000 MassGIS Networked Hydro Centerlines and 1:24,000 USGS National Hydrography Dataset (NHD) in the Parker River NWR acquisition boundary.

### *5.1.3 Wetlands*

The WRIA relies on the National Wetland Inventory (NWI) maps to inventory the extent of wetland habitat at Parker River NWR. The NWI is a branch of the Service established in 1974 to provide information on the extent of the nation's wetlands (Tiner 1984). NWI produces maps of wetland habitat as well as reports on the status and trends of the nation's wetlands. Using the *Classification of Wetlands and Deepwater Habitats of the United States* (Cowardin et al 1979) wetlands have been inventoried and classified for approximately 90% of the conterminous United States and approximately 34% of Alaska. Cowardin's classification places all wetlands and deepwater habitats into 5 "systems": marine, estuarine, riverine, lacustrine, and palustrine. Most of the wetlands in the United States are either estuarine or palustrine (Tiner 1984). The predominant wetland classes at the refuge are defined in Cowardin et al (1979) as:

> **Estuarine:** The Estuarine System consists of deepwater tidal habitats and adjacent tidal wetlands that are usually semi-enclosed by land but have open, partly obstructed, or sporadic access to the open ocean. The Estuarine System extends (1) upstream and landward to where ocean-derived salts measure less than 0.5% during the period of average annual flow; (2) to an imaginary line closing the mouth of a river, bay, or sound; and (3) to the seaward limit of wetland emergents, shrubs, or trees where they are not included in (2).
>
> **Palustrine**: The Palustrine System includes all nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean derived salts is below 0.5% (e.g., inland marshes, bogs, fens, and swamps).

The different systems can be broken down into subsystems, classes and hydrologic regimes based on the wetland's position in the landscape, dominant vegetation type, and hydrology.

NWI wetland classifications were completed for the Parker River area in 2013. The salt marshes and tidal flats of Plum Island Sound are the most extensive wetland types within the acquisition boundary (60% / 3855 acres). Refuge impoundments and the numerous small freshwater wetlands in Plum Island's dune field make up a much smaller portion of the wetlands in the acquisition boundary (6% / 366 acres) (Table 5 and Figure 8).

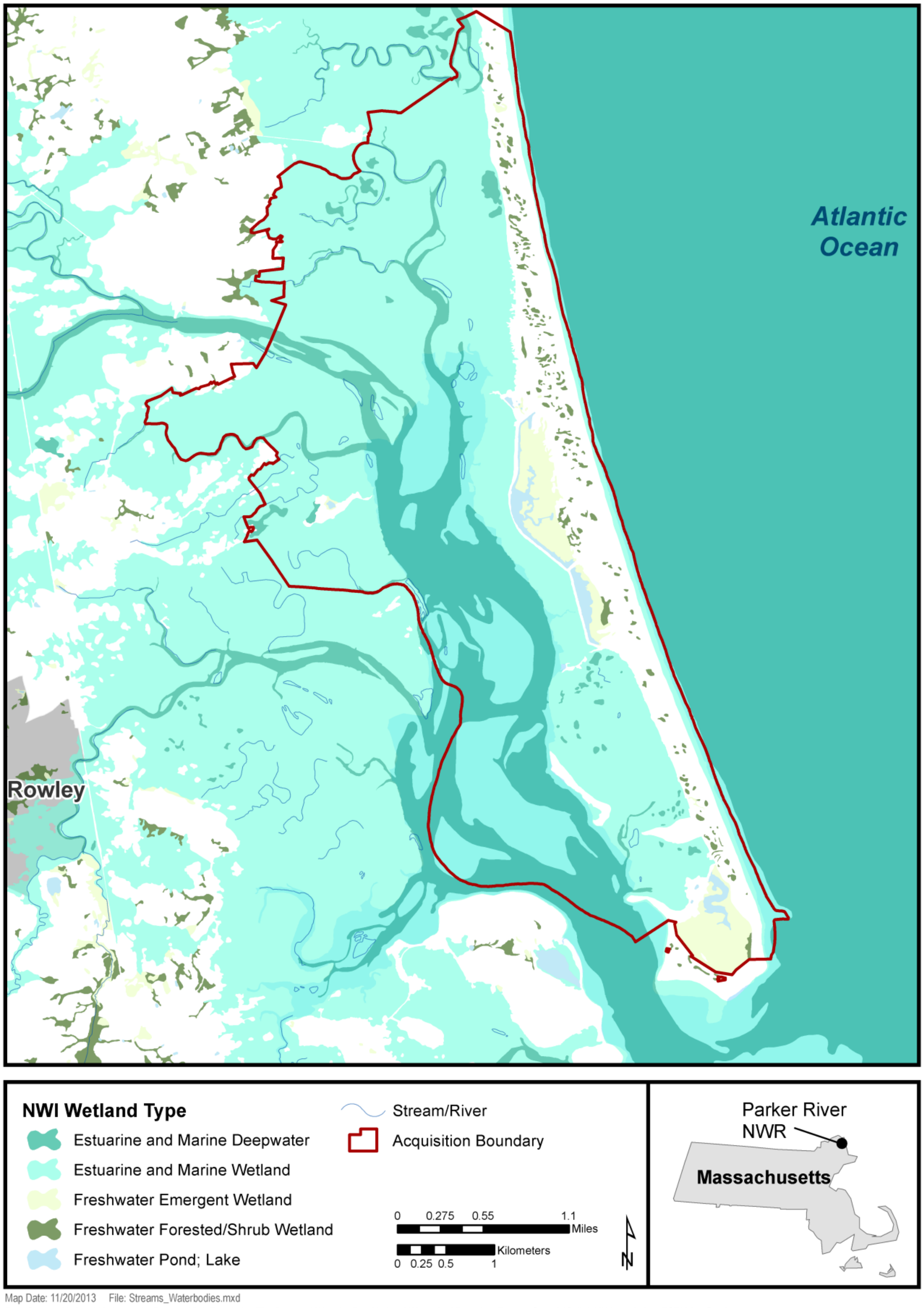



Figure 8. National Wetland Inventory wetlands in the Parker River NWR acquisition boundary and surroundings.

Table 6. Wetland habitat delineated by the National Wetland Inventory inside the Parker River NWR acquisition boundary.

| Wetland Type | Acres on refuge | Percent of total area |
|---|---|---|
| Estuarine and Marine Deepwater | 1200.8 | 18.8 |
| Estuarine and Marine Wetland | 3855.1 | 60.4 |
| Freshwater Emergent Wetland | 225.3 | 3.5 |
| Freshwater Forested/Shrub Wetland | 73.3 | 1.1 |
| Freshwater Pond | 36.3 | 0.6 |
| Lake | 31.0 | 0.5 |
| ***Total*** | ***5421.8*** | ***84.9*** |

### *5.1.4 Interdunal Swales*

A unique wetland feature at Parker River NWR are interdunal swales. Interdunal wetlands are common features in many dune systems around the world (i.e. Winter 1986, Doss 1993, Sacks et al 1992). They are emergent wetlands that from in depressions between sand dunes where the water table is near or above the ground surface. These features are hydrologically isolated from other water sources and water levels in the wetlands fluctuate as the water table rises and falls with changing precipitation patterns. Interdunal swales are rare in Massachusetts and the state considers them critically imperiled (S1) (Swan and Kearsley 2001, NHESP 2011). There are many small swales on the refuge and the refuge considers them important habitat as they are the only natural freshwater wetlands on the refuge (Nancy Pau, personal communication).

### *5.1.5 Groundwater*

Groundwater near Parker River NWR is found in Valley-Fill Glacial Aquifers and Crystalline Rock aquifers in eastern Massachusetts. These aquifer systems are described generally in the Groundwater Atlas of the United States (Trapp and Horn 1977). A more detailed review of groundwater resources in Massachusetts can be found in Simcox's "Water Resources of Massachusetts" (1992). Groundwater conditions specific to Parker River NWR are discussed in Smith's 1985 investigation into sources of freshwater for the refuge's impoundments, available at the refuge office.

Most of the aquifers in the eastern portion of the Parker River watershed consist of sandy glacial-outwash deposits, which are typically thinner and less permeable than the coarse sand and gravel deposited by streams that drained melting glacial ice. The coarse sand and gravel deposits form the Valley-Fill Glacial Aquifers defined by Trapp and Horn (1977). Simcox (1992) refers to these deposits as "stratified-drift aquifers" or "ice-contact deposits. These aquifers tend to be found in valley bottoms and are more common in the western half of the watershed (see Figure 3). Because of their relative thickness and coarse sediments, the stratified-drift aquifers store considerable groundwater and are important water sources for industry and municipalities (Simcox 1992). In the Parker River watershed these aquifers are most common west of I-95 and are thought to have a good hydrologic connection with the river (Simcox 1992) (Figure 11; Section 5.2.4).

On the refuge, groundwater is found in crystalline bedrock and the dune sediments of Plum Island. Bedrock under the refuge is primarily quartz and is between 50 and 100ft below land surface (Smith 1985). Water in this aquifer is stored in the fractures in the bedrock. In many parts of Massachusetts, water in bedrock fractures is used for domestic water supplies (Simcox 1992). However, because the fractures are not extensive and the aquifer is underneath shallower sediments, this aquifer has little interaction with wetlands and streams at the ground surface.

Coastal barrier islands like Plum Island often have a shallow freshwater aquifer. This freshwater is derived from precipitation that infiltrates through the dune sediments. Freshwater in the dunes forms a “lens” that floats on the more saline groundwater that has infiltrated from the surrounding ocean and sound. (Masterson et al 2013).

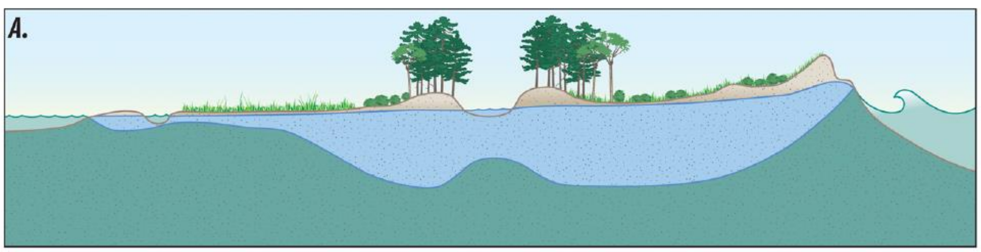



Figure 9. Schematic of a freshwater lens (shown in blue) underneath a coastal barrier island. Saline groundwater is shown in green (from Masterson et al 2013).

At Parker River NWR, the freshwater lens supports the interdunal swale wetlands. The depth to water in the wetlands fluctuates seasonally as the water table rises and falls. Water levels are typically highest in the winter months and early spring, prior to the onset of the growing season. Water levels tend to drop as temperatures increase and the coastal vegetation utilizes the shallow groundwater for transpiration.

Smith (1985) evaluated the feasibility of using the freshwater lens on Plum Island as a water source for the refuge’s wetland impoundments. His report estimated that a shallow well field could be constructed adjacent to North and South Pools and provide approximately 0.42 million gallons per day. However, he also indicated that construction of such a system would lower the water level in shallow interdunal wetlands near the pumping field. Because, the aquifer in the Plum Island dunes is not particularly large even this relatively low pumping rate has the potential to cause saltwater intrusion into the freshwater lens (Smith 1985). Due to the limited freshwater sources, a well field was never constructed to supplement the water supply of the Parker River impoundments.

#### *5.1.6 Plum Island Sound*

The refuge acquisition boundary includes a large portion of Plum Island Sound. The salt marshes, tidal flats, and shellfish beds of the Sound are important resources for numerous fish and wildlife species (Brown 2001, Buchsbaum et al 2002, MCZM 2000). Plum Island Sound and its surrounding salt marshes are part of the "Great Marsh," a nearly 25,000 acre area of salt marsh, mud flats, and barrier islands that stretches from Essex Bay near Gloucester, MA to the Merrimack River in Hampton, NH. The Great Marsh represents the largest continuous salt marsh area in New England (Great Marsh Coalition, MCZM 2000). The portion of the Great Marsh that includes Plum Island Sound and Essex Bay was identified as an Area of Critical Environmental Concern (ACEC) by the Massachusetts Department of Environmental Management (DEM) in 1979 (MCZM 2000). This designation was made due the outstanding natural qualities of the coastal salt marshes and, at the time of designation, the relatively undisturbed nature of the marshes and barrier islands in the ACEC (MCZM 2000).

Plum Island Sound is relatively shallow, with an average depth that ranges from about 10 ft at Mean High Water to 5 ft at Mean Low Water. Approximately 78% of the sound is between 0 and 6 ft deep at Mean Low Water (Buchsbaum et al 2002) and average tidal range is approximately 9 ft (Vallino and Hopkinson 1998). Water entering the sound is typically flushed from it in a matter of days (Vallino and Hopkinson 1998). The low residence time and rapid flushing is thought to help keep Plum Island Sound's salinity closer to ocean levels than other Massachusetts estuaries (Buchsbaum et al 2002).

### 5.2 Water Related Infrastructure

Water related infrastructure refers to the assets at a refuge that create or support refuge water resources and objectives. Examples include impoundments for waterfowl habitat, water control structures and water supply wells used to maintain wetland habitat. Many of these types of features are accounted for in the National Wildlife Refuge System's Service Asset Maintenance Management System (SAMMS) database. The aim of the WRIA is to summarize information and provide additional context on a refuge's water resource infrastructure.

Parker River NWR's water related infrastructure is used primarily for managing three waterfowl impoundments for waterbirds. These managed wetlands are being manipulated by refuge staff using infrastructure such as dikes and water control structures. Other infrastructure that affects water resources in the vicinity of the refuge is also discussed below.

#### *5.2.1 Impoundments*

There are three brackish water impoundments on the refuge totaling 262 acres: the North Pool, the Bill Forward Pool and the Stage Island Pool (Figure 10). The impoundments were created in the mid-1900s by building 2.3 miles of dikes to provide black duck habitat. The water sources for these impoundments are precipitation and water from the sound, which are used to flood them during winter and spring. Bill Forward and Stage Island pools are both brackish, whereas North Pool can be freshwater or brackish depending on how it is managed (Nancy Pau, personal communication). Water levels in the pools are lowered to expose mudflats for shorebird feeding and resting during migration, and elevated during waterfowl migration. Since 2006, refuge staff have kept water levels higher in the North Pool during the growing season to support breeding rail and other secretive marsh birds. According to the refuge's 2011-2012 Annual Habitat Work Plan, management prescriptions will change from year to year, depending on wetland dynamics and vegetative composition, but will be directed to provide the following each year:

1. Migrating shorebirds: shallow water (<10 inches water depth) to mudflat habitat with sparse (<15% cover) to no vegetation, at time of peak migration (late May and early August)

2. Fall migrating waterfowl: shallow flooded (<12 inches) annual vegetation composed primarily of *Cyperus*, *Echinochloa*, *Polygonum*, *Bidens* and other seed producing moist soil vegetation at time of peak migration (late October to early November)

3. Manage for breeding marsh birds (e.g. clapper rail, American bittern, virginia rail, least bittern, marsh wren, sora) and waterfowl (e.g. black duck, green-winged teal, gadwall) by maintaining water levels and controlling invasive plants (USFWS 2012).

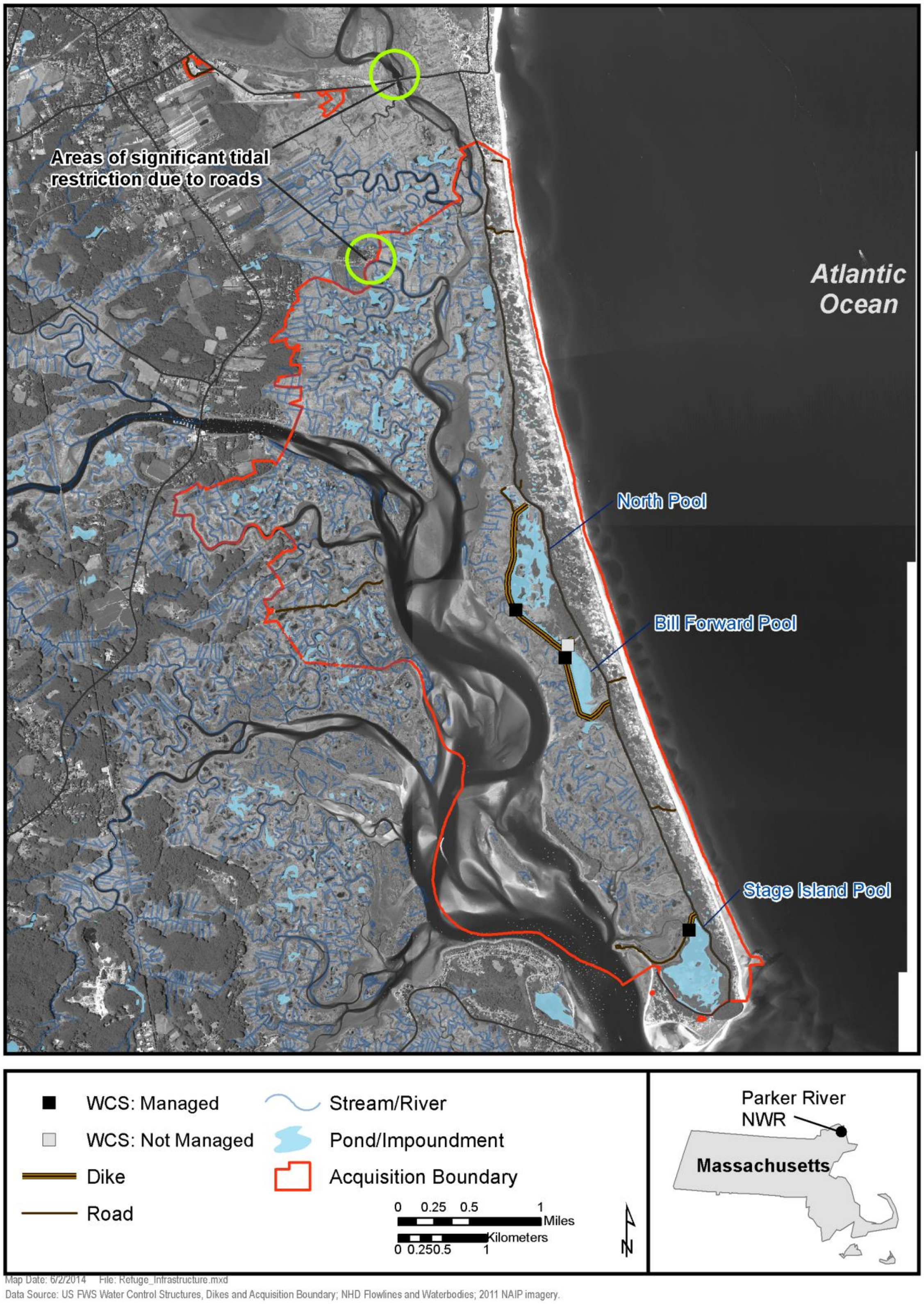



Figure 10. Impoundments and water control structures at Parker River NWR.

### *5.2.2 Water-control structures*

There are a total of 4 water control structures at Parker River NWR. Each of the wetland impoundments has one water control structure to connect it to the Plum Island Sound. There is also an additional un-managed structure that connects North Pool to Bill Forward Pool but it is no longer-functional (Figure 10). Water control structures are the stop-log riser variety typically found on wildlife refuges around the country. The North Pool and Stage Island structures are outfitted with screw gates. The structure on Bill Forward pool has aluminum stop logs, some of which have flaps designed to prevent saltwater from flowing through the structure and into the impoundment.

### *5.2.3 Off-Refuge Surface Water Sources*

The principle off-refuge surface water sources are the Parker and Ipswich rivers that flow into Plum Island Sound (Figure 7). The Merrimack River also contributes freshwater to the Sound via the Plum Island River (Zhao et al 2010).

The Parker River originates in the town of Boxford as a series of headwater ponds. The River drains an area of 82 square miles and flows approximately 21 miles east before emptying into Plum Island Sound on the west side of the refuge (MCZM 2000, Gomez and Sullivan 2003). Major tributaries to the Parker River are the Mill and Little Rivers.

The Ipswich River drains an area of 155 square miles and empties into the southern portion of Plum Island Sound, near the southern tip of the refuge acquisition boundary (Simcox 1992, MCZM 2000). Because the Ipswich enters the Sound near its mouth, freshwater from the Ipswich River has less influence on the salinity and water quality of the Sound than the Parker River (Buchsbaum et al 2002).

Located between the Parker and Ipswich rivers are the Rowley and Eagle Hill rivers; the Rowley, combined with the Egypt River, drains an area of 9.6 square miles, while the Eagle Hill river drains an area of 12 square miles (Gomez and Sullivan 2003).

The Merrimack River drains 5,000 square miles in Massachusetts and New Hampshire and enters the Atlantic Ocean north of Parker River NWR. Recent hydrodynamic modeling of the Merrimack River / Plum Island Sound estuarine system shows the two water bodies are hydraulically connected (Zhao et al 2010). At high tide and during periods of high river discharge, relatively fresh water from the Merrimack can flow into Plum Island Sound via Plum Island River. Conversely, during ebb tides and low runoff conditions in the Merrimack, Plum Island River carries relatively saline water from Plum Island Sound into the Merrimack River Estuary. Additionally, longshore currents along the Atlantic shore of Plum Island, carry some Merrimack River water to the southern entrance of Plum Island Sound near Ipswich (Zhao et al 2010).

#### *5.2.4 Off-Refuge Water Diversions*

Both the upper watersheds of the Parker and Ipswich rivers have surface water and groundwater diversions that contribute to low flow conditions during the summer months (Figure 11). Diversions are primarily to support municipal water supply and have dried sections of both rivers on multiple occasions (MCZM 2000, Gomez and Sullivan 2003, Claessens et al 2006, Horsley Witten Group 2008). These extreme low flow conditions are the result of the combined effects of three activities: 1) surface and groundwater withdrawals for public and private consumption within the watersheds; 2) surface and groundwater withdrawals that are transferred to public and private users outside the watersheds; and 3) transfer of wastewater to treatment plants that discharge outside of the watersheds.

Although the impacts of municipal water use are most acute in the upper sections of the Parker and Ipswich watersheds, there are implications for freshwater supply to the Plum Island Sound. Reductions in streamflow from water diversions can alter the salinity of the estuary, reduce sediment transport, increase stream temperatures, and interfere with fish migration (Armstrong et al 2001).

Gomez and Sullivan (2003) report that water withdrawals for public water supply and industrial uses can cause severe ecological stress on freshwater habitat in the Parker River. The majority of withdrawals within the watershed (84%) are from public and private groundwater wells (Bratton 1991, Castonguay, personal communication). The largest water user in the watershed is Georgetown Water Department. The town supplies water to its citizens by pumping groundwater from wells adjacent to the Parker River upstream of Rock Pond. Georgetown's water use increased 48% between 1990 and 2001 as the suburban population of the community grew (Gomez and Sullivan 2003). The Parker River watershed has somewhat limited capability to support anthropogenic water demands because of the relatively small size of the watershed and the limited extent of stratified drift aquifers (Horsley and Witten Group 2008). Lawn irrigation during the summer months places the greatest demands on town water supplies (Gomez and Sullivan 2003, Horsley Witten Group 2008). Water conservation actions that aim to reduce summer water use are thought to be the best way to improve summer flow conditions in water stressed reaches of the Parker River (Horsley Witten Group 2008).

Adequate water supply in the Ipswich River drainage has been an issue for many years. In 1997 and 2003, American Rivers declared the Ipswich one of the most endangered rivers in the United States due to extreme low flows (IRWA 2012). Although nearly 25% of the Ipswich River watershed is conservation land, many of the towns in the watershed are bedroom communities of Boston. Towns in and near the watershed have experienced considerable population growth throughout the 1900s (Claessens et al 2006). Today the river and its tributaries are the water source for more than 330,000 people in 14 different communities (IRWA 2012). Surface water is withdrawn from the river to support municipal supplies for the towns Lynn, Peabody, Salem, and Beverly. Other communities in the watershed rely on groundwater pumped from wells and/or diversions from water storage reservoirs (Zariello and Ries 2000). Because many diversions are routed to wastewater treatment plants outside of the river basin, only 10 to 20 percent of the water withdrawn from the Ipswich returns to the river as wastewater (Zariello and Ries 2000). Surface water diversions typically occur during periods of high flow and their impact on streamflow is thought to be less significant than the impact from groundwater withdrawals from wells, which are more widespread and occur year-round (Zariello and Ries 2000).

USFWS New England Flow Policy identifies August streamflows as the most critical time of the year for aquatic species (USFWS 1999, MA WRC 2008). Typically, eastern Massachusetts streams reach their lowest levels in August and September. These months can be periods of stress for aquatic species even under unaltered flow conditions (Armstrong et al 2001). Groundwater pumping has the greatest impact on August streamflow in the western portions of the watersheds near their headwaters (see Figure 12, Weiskel et al 2010). These areas are expected to be particularly sensitive to water diversions because the watersheds are relatively small and the surficial geology is not conducive to groundwater storage (Horsley and Witten Group 2008). Due to the diversions in the watersheds portions of both the Ipswich and Parker River are listed as impaired due to flow alterations on the 2012 Massachusetts Integrated List of Waters.

Groundwater wells tend to be placed in stratified drift aquifers near the Parker and Ipswich rivers. These withdrawals deplete streamflow by intercepting groundwater that normally discharges to the river or by inducing seepage from the stream toward the pumping well (Armstrong et al 2001). Groundwater withdrawals are thought to have contributed to severe low flows that dried river reaches and contributed to fish kills on the Ipswich during the summers of 1995, 1997, 1999, 2001, 2002, 2003, and 2005 (IRWA 2012). Communities that rely on Ipswich and Parker River water are beginning to modify water use practices inside their boundaries in an effort to improve streamflow conditions in the river. In 2006, the Town of Reading switched from using groundwater wells near the Ipswich River to the regional water supply system operated by the Massachusetts Water Resources Authority (MWRA) (Wolheim et al 2013). Water use by Reading contributed significantly to low flow conditions in the Ipswich (Zariello and Ries 2000) and this switch has been associated with improvements in Ipswich River flows (IRWA 2012).

#### *5.2.5 Upstream Dams*

Rivers in Massachusetts have some of the highest concentrations of dams in the United States (Weiskel et al 2010). The WRIA did not uncover specific information related to how dams on the Ipswich or Parker Rivers impact Plum Island Sound or Parker River NWR. However, there are numerous dams in the rivers' watersheds (see Figure 11) and it is likely they affect runoff patterns and sediment supply to the Sound. Dams alter runoff patterns by reducing the magnitude of flood events and extending the duration of low flow periods (Weiskel at al 2010). Additionally, they reduce the sediment supply to coastal waters (Weiskel et al 2010) which can influence sediment accretion in salt marshes. The impounded sections behind dams raise water temperatures and contribute to lower dissolved oxygen concentrations in rivers (Weiskel et al 2010). Perhaps the most obvious impact of dams, are the physical barriers they create that impede aquatic species migrations (Collier et al 1996, Weiskel et al 2010).

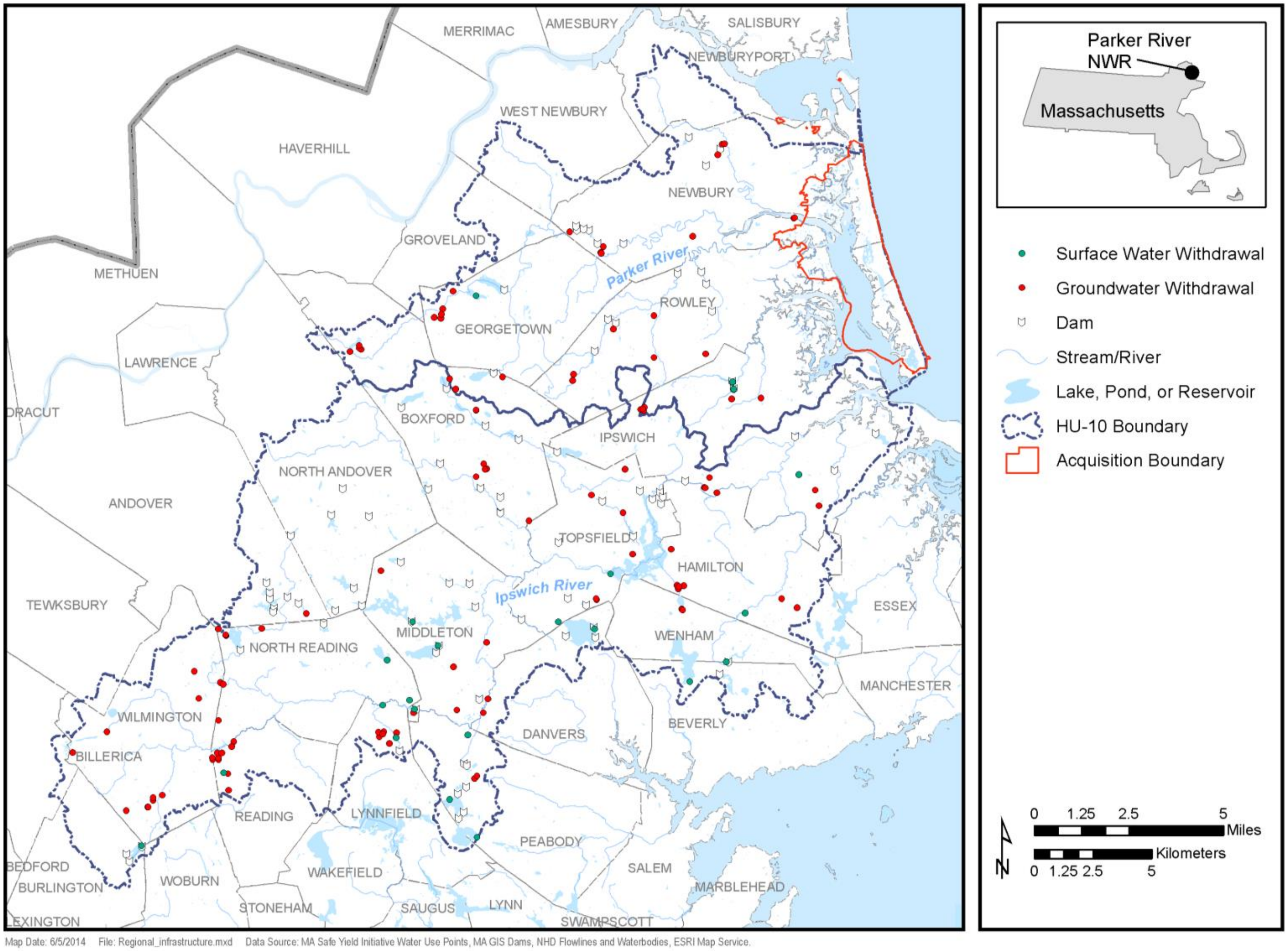



Figure 11. Regional infrastructure related to water management affecting low flow conditions, including Water Management Act (WMA) permitted surface and groundwater withdrawal sources

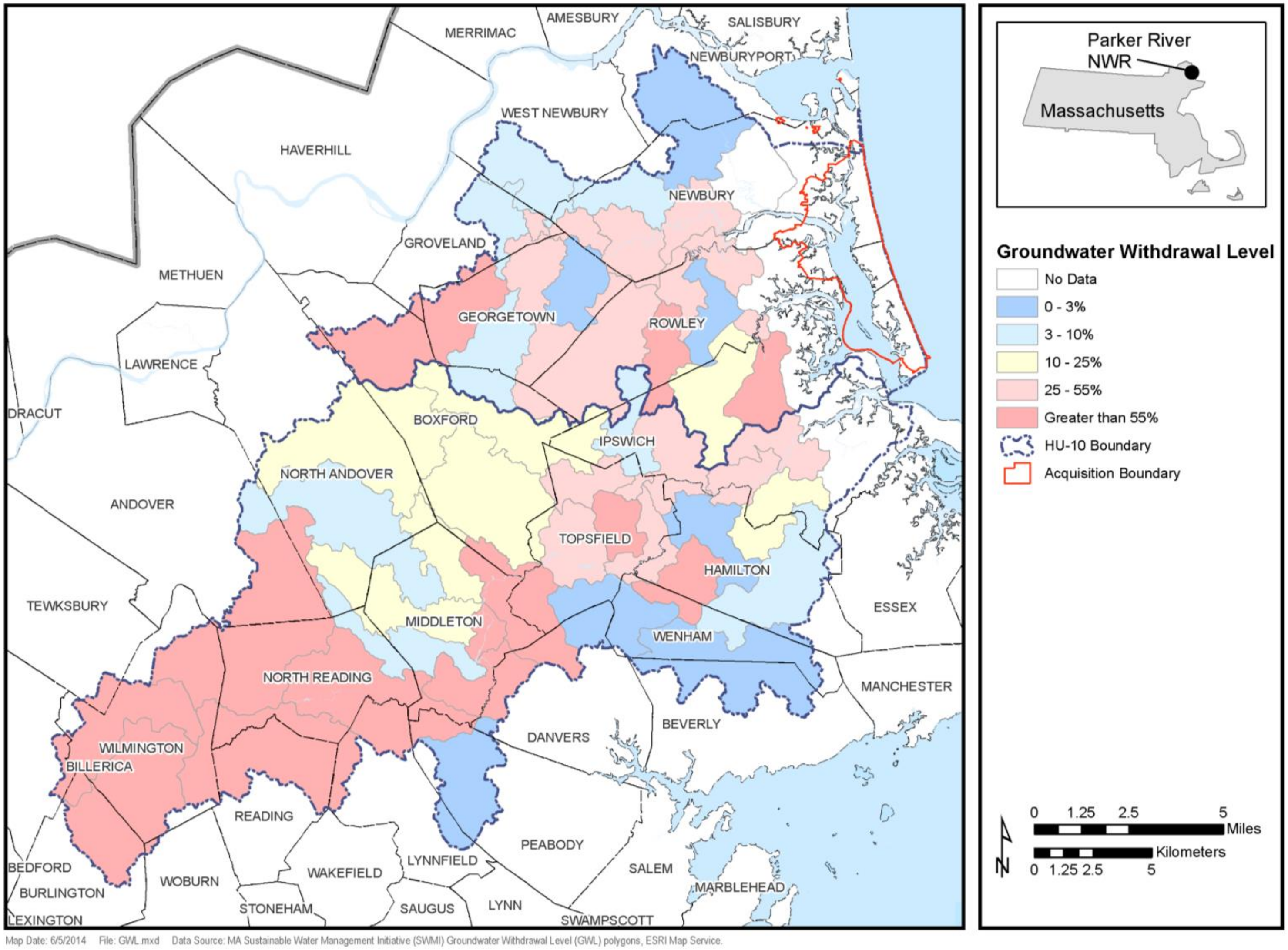



Figure 12. Massachusetts Sustainable Watershed Management Initiative (SWMI) Groundwater Withdrawal Level (GWL) percent August streamflow alteration for the Parker and Ipswich River watersheds.

### *5.2.6 Mosquito Control Ditches and Open Marsh Water Management*

Grid ditching salt marshes in an effort to reduce mosquito habitat was a common practice in the marshes of the Northeast in the 1930s and as recently as the 1960s. Although the practice is no longer an accepted tool for mosquito control, the ditches persist in the majority of salt marshes between Virginia and Maine (Roman et al 2000). Ditches negatively affect salt marsh habitat by lowering marsh water levels, shifting vegetation, and draining marsh pools and pannes (Roman et al 2000, James-Pirri et al 2008). Relict mosquito control ditches are common in the salt marshes of Plum Island Sound (MCZM 2000, Buchsbaum et al 2002) and Parker River NWR (James-Pirri et al 2008).

The Northeast Massachusetts Mosquito Control and Wetlands Management District (District) uses a variety of techniques to control mosquito populations in salt marshes of Essex, Winthrop, and Revere counties, including marshes of Plum Island Sound. These methods include use of insecticides, ditch maintenance, and water management strategies known as Open Marsh Water Management (OMWM). From 1984 – 2009, the Refuge partnered with the Mosquito Control District to implement OMWM in Refuge salt marshes between the maintenance building and Lot 2. The OMWM approach is thought to have less ecological impact than grid ditching (Buchsbaum et al 2002) and larviciding while also improving bird habitat. However, the results of the Region 5 OMWM study (James-Pirri et al 2008) and changing salt marsh hydrology associated with sea level rise have raised concerns about the impacts of ditch plugging. In some cases, ditch plugs can create conditions that are too wet. The Refuge stopped OMWM activities in 2006 and the District's permit for OMWM activities in Plum Island Sound salt marshes has not been renewed since 2009. The Refuge is currently working with the Mosquito Control District to remove 2 ditch plugs to evaluate the role ditch plugs play in the transition from high marsh (*Spartina patens*) to low marsh (*Spartina alterniflora*) (Nancy Pau, personal communication).

### *5.2.7 Roads*

The refuge maintains 11 miles of road and 2.6 miles of trails on Plum Island (Figure 10), which include boardwalks, gravel, and hard surfaces. Roads can degrade aquatic habitat by increasing sedimentation, fragmenting habitat, and providing pathways for invasive species (Gucinski et al 2000). Roads constructed across salt marshes often have undersized culverts or bridges creating choke points that limit water movement in tidal channels. These tidal restrictions can alter natural inundation patterns in wetlands upstream of the restriction and contribute to erosion and sedimentation in the tidal channels (Roman et al 2000). Because they limit seawater movement, tidal restrictions cause sections of a salt marsh to become less saline (Roman et al 2000, Buchsbaum et al 2002) which facilitates the expansion of *Phragmites australis* into the marsh (Buchsbaum et al 2006).

The Parker River Clean Water Association inventoried tidal crossings in the Great Marsh ACEC in 1996 and found 46 tidal crossings, 11 of which were considered "significant" because they restrict tidal flow more than 5 inches at the crossing (MCZM 2000, Buchsbaum et al 2002). On the refuge, the impoundment dike and the refuge road are barriers to the landward migration of adjacent salt marshes. Off-refuge, the Plum Island Turnpike and Pine Island Road restrict tidal flow in channels northeast of the refuge (see Figure 10). Multiple projects have been completed or are underway to restore areas of the Great Marsh affected by tidal restrictions (MCZM 2000, Buchsbaum et al 2002, DCR 2005, Buchsbaum et al 2006) and the refuge is currently planning restoration strategies for tidally restricted areas on refuge salt marshes (Nancy Pau, personal communication).

## 5.3 Water Quality

Water quality information included in the WRIA is usually derived from the Reach Access Database (RAD) maintained by the U.S. Environmental Protection Agency (EPA). Additional data are publically available at the EPA's "Envirofacts" website. These databases were used to collect information on listed waters and National Pollutant Discharge Elimination System (NPDES) permits in and around the refuge. RAD data available online for the area around Parker River NWR is current through 2004, and NPDES information was frozen as of 2006, due to a planned migration to a new information system.

### *5.3.1 Clean Water Act Impairments and TMDLs*

Section 303(d) of the Clean Water Act requires that each state identify water bodies where water quality standards are not met. The Massachusetts Department of Environmental Protection (MassDEP) develops lists of known water quality limited rivers and lakes. The latest Massachusetts Integrated List of Waters (ILW) was published in 2012 (MassDEP 2012) and lists the waterbodies shown in Table 7 as impaired.

Total Maximum Daily Loads (TMDL) are developed for impaired water bodies. TMDLs are documents prepared by EPA or MassDEP that define: 1) how much of a pollutant can be discharged into the waterbody each day without violating water quality standards and 2) distribute the total daily load to all significant point and non-point sources of the pollutant to the waterbody in question (USEPA 1998). The 2012 ILW indicates the entire areas of the Plum Island River, Parker River, and Plum Island Sound within the refuge acquisition boundary are required to carry TMDLs for pathogens or fecal coliform (Figure 13). Fecal coliform is a measure of pathogens that can be harmful to human health. The source of elevated fecal coliform levels is excess raw sewage. Failing septic systems, discharge from marine vessels, and runoff from agricultural facilities with livestock have all been identified as potential sources of excess sewage in the Parker River watershed (MassDEP et al undated, Buchsbaum et al 2002, Rickards et al 2002, DCR 2005). In addition to the listings for water quality contamination, a 12.3-mile segment of the upper Parker River is considered impaired due to low flow alterations (2012 ILW).

Like the Parker River, the Ipswich is also impaired due to elevated levels of fecal coliform. The Ipswich River basin contributes approximately 50 to 80 percent of all fecal coliform loading to Plum Island Sound (MCZM 2000). Additionally, a draft TMDL for nutrients was scheduled to be completed for the Ipswich River in the first quarter of 2012.

Table 7. Impaired waterbodies within Parker River NWR acquisition boundary (MassDEP 2010, 2012).

| Name/Description | Waterbody ID | Impairment | Acres within acquisition boundary |
|---|---|---|---|
| **Parker River** | | | 145 |
| Central Street to mouth at Plum Island Sound, Newbury. | MA91-02_2010 | Fecal Coliform | |
| **Plum Island River** | | | 296 |
| From "high sandy" sandbar just north of the confluence with Pine Island Creek, Newbury to confluence with Plum Island Sound, Newbury. | MA91-15_2010 | Fecal Coliform | 262 |
| From Chaces Island, Merrimack River Estuary, to the "high sandy" sand bar just north of the confluence with Pine Island Creek, Newbury (formerly encompassed in MA84A-23). | MA84A-27_2010 | Pathogens | 35 |
| **Plum Island Sound** | | | 1572 |
| From the mouth of both the Parker River and Plum Island River, Newbury to the Atlantic Ocean, Ipswich (Includes Ipswich Bay). | MA91-12_2010 | Fecal Coliform | |
| ***Grand Total*** | | | ***2013*** |

### *5.3.2 NPDES Permits*

NPDES permits are issued to businesses by MassDEP to regulate the quality and quantity of pollutants discharged into waters of the United States. Stormwater and treated wastewater are two examples of discharges regulated under the NPDES program. The permit requires the permittee to conduct monitoring of select parameters, based on the nature of the industry, at defined frequencies. Parameters may include measures of water quantity (e.g., flow) and water quality (e.g., nutrients, bacteria, suspended solids, pH). There are several regulated facilities with NPDES permits in the vicinity of the refuge (Table 8, Figure 13). Three sites, (5, 6 and 7 in Table 8) discharge wastewater into the tributaries of the Parker, Rowley, and Ipswich Rivers. Site 5, includes wastewater from the Governor's Academy and sites 6 and 7 include wastewater from the Town of Ipswich. It is expected that contaminants discharging from these facilities and others eventually find their way to Plum Island Sound.

Table 8. NPDES permitted sites near Parker River NWR. Links to online permit documents have been provided where available.

| # on Figure 13 | Facility Name | Permit Number | Town_Name | Date issued |
|---|---|---|---|---|
| 1 | FERRAZ SHAWMUT, INC | MA0000281 | NEWBURYPORT | 9/30/2002 |
| 2 | NEWBURYPORT W P C F | MA0101427 | NEWBURYPORT | 8/15/2012 |
| 3 | INNOVATIVE TECHNOLOGIES | NPDES – unpermitted | NEWBURYPORT | |
| 4 | HERO COATINGS INC. | MA0039985 | NEWBURYPORT | |
| 5 | GOVERNOR DUMMER ACADEMY* | MA0030350 | NEWBURY | 9/28/2011 |
| 6 | IPSWICH WATER TREATMENT PLANT | MAG640025 | IPSWICH | |
| 7 | IPSWICH W W T F | MA0100609 | IPSWICH | 2/20/2003 |

*The Governor's Academy

### *5.3.3 Mercury Contamination*

A 2004-2007 study on mercury exposure in saltmarsh sharp-tailed sparrows on four NWRs in New England found levels to be highest in sparrows at Parker River NWR (Major and Pau 2008). Similarly, a 2009 study found that mercury levels in common eiders on the refuge averaged much higher than those of individuals of the same or similar species in other parts of North America (Meattey and Savoy 2010). In 2010 and 2011 the refuge sampled the Rowley and Egypt rivers, Plum Island Sound and Plum Island River along with four areas with a high density of salt panne habitat. Total mercury concentrations were found to be higher along the rivers than within the sound, and salt panne habitats were found to have the highest levels of methyl mercury. The results indicate that tidal flushing dilutes total mercury and methyl mercury, and mercury methylation is higher in areas with more organic matter (e.g., salt pannes) (USFWS 2012). Northeastern Massachusetts is considered a mercury "hotspot" due to municipal solid waste combustors and medical waste incinerators. Though the specific pathways contributing to the mercury load on the refuge are unknown, upstream segments of the Parker, Merrimack and Ipswich Rivers and tributaries have impairments for mercury in fish tissue (MassDEP 2012). Fortunately, the state of Massachusetts has made good progress on reducing mercury emissions from industry (Major 2013).

### *5.3.4 Boat Waste*

Many of the studies of the Plum Island Sound have documented the negative impact of boat-waste on the water quality of the estuary (MCZM 2000, Brown 2001, Buchsbaum et al 2002, Richards et al 2002). The Plum Island Sound is a popular site for recreational boating; on a sunny weekend as many as 200-300 boats may anchor off Plum Island and Crane Beach (Brown 2001). Although EPA and the U.S. Coast Guard have cooperated to define minimum treatment requirements for boat waste, in areas of poor tidal flushing or high concentrations of boating activity, discharges from boats can still have negative impacts on water quality (Brown 2001). As recreational boating has grown in popularity, uncontrolled discharges from vessels in Plum Island Sound and its rivers are a direct source of pathogens that impair water quality. The Massachusetts Coastal Zone

Management Office (MCZM) designated the north coastal waters, which include Plum Island Sound, as No Discharge Zone (NDZ) in 2010 and in June 2014, all coastal waters of Massachusetts were designated NDZs. Both treated and untreated discharges from boat waste is prohibited in NDZs (Brown 2001). To facilitate compliance with the NDZ designation, the state funds the operation and maintenance of stationary pumpout facilities and pumpout boats at marinas in Ipswich, Rowley, and Newbury. Recreational vessels can use these facilities to comply with the NDZ regulations and ensure their boat waste is kept out of the Sound.

### *5.3.5 Contaminant Assessment Process*

Water quality concerns at the refuge were summarized in the 2013 Contaminants Assessment Report prepared by the New England Ecological Services Field Office (Major 2013). The report summarizes the challenges posed by mercury contamination at Parker River (see Section 5.3.3) and recognizes that water quality in the Plum Island Sound is contaminated from sewage, particularly during periods of heavy rain. The Merrimack River, north of the refuge, was highlighted as a potential source of contamination for the refuge. The Merrimack drains a much larger watershed than either the Parker or Ipswich rivers and development in its watershed contributes to it being impaired for heavy metals, pathogens, algal growth, and pH. Contaminants from the Merrimack can reach the refuge via the tidal Plum Island River or via longshore currents that carry Merrimack River water south from its mouth to the refuge's beaches (Zhao et al 2010, Major 2013).

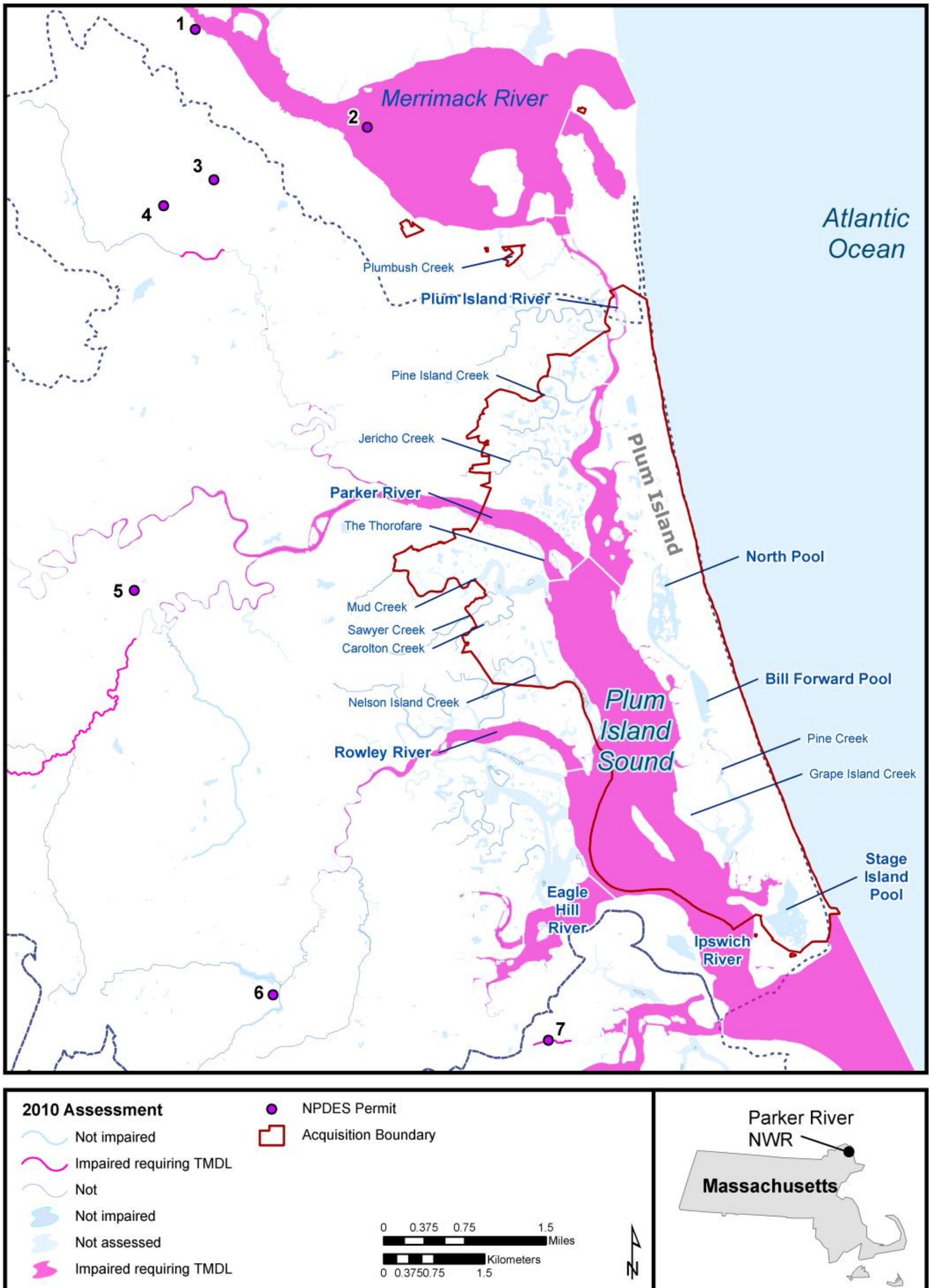
### *5.3.6 Nutrients*

Nitrogen is often the limiting nutrient for plants in wetlands and coastal waters. The addition of Nitrogen to the landscape through human activities is recognized as the one of the primary causes of impaired water quality in aquatic ecosystems (Mitsch and Gosselink 2000). Several studies have evaluated nitrogen loading in the rapidly urbanizing watersheds that feed Plum Island Sound (Tobias et al 2003, Filoso et al 2004, Williams et al 2004, Weston et al 2010). In general these studies have focused on nitrogen loading in the watersheds and have attempted to quantify or model nitrogen transport and uptake in the rivers and the Sound. The primary sources of excess nitrogen in Plum Island Sound watersheds are septic systems, fertilizer application, and atmospheric deposition (Filoso et al 2003, Williams et al 2004). Nitrogen loading is predicted to continue to increase with suburban development (Filoso et al 2003). Because of its rapid flushing rate (Vallino and Hopkinson 1998), Plum Island Sound is perhaps less sensitive to nitrogen loading than other estuaries (Tobias et al 2003). However, in the upper reaches of the estuary, water residence times can approach several weeks during the summer months when freshwater streamflow is at its lowest (Vallino and Hopkinson 1998). At these times, excess nitrogen in the system is more likely to contribute to localized algal blooms that contribute to poor water quality (Weston et al 2010).

### *5.3.7 Water Quality Overview*

The primary water quality concern at Parker River NWR is contamination from untreated human and animal waste in the watersheds that contribute to the Plum Island Sound. The causes of contamination are related to development in the Parker and Ipswich River watersheds and tightly coupled with stormwater runoff (Keane and Castonguay 2000). Failing septic tanks, agricultural runoff, inadequate wastewater treatment, and discharges from marine vessels all contribute to the fecal coliform impairment of the Sound and its rivers (MCZM 2000, Rickards et al 2002, DCR 2005). Massachusetts Audobon's Minibay Project of the mid-1990s, found that the Ipswich River contributes nearly 90% of the fecal coliform loading to the Plum Island Sound. Most of this loading comes from the reach of the river between Ipswich (Sylvania) Dam and the Ipswich town wharf (Buchsbaum et al 2002). However, because the Ipswich enters the Sound so close to its mouth, most of the Ipswich's water is quickly flushed from the Sound into the Atlantic. Contamination in the Parker River watershed affects the Sound's water quality more, because the river empties into the upper reaches of the Sound. The Little Creek and Mill Creek tributaries of the Parker River are particular hotspots for fecal coliform because they drain heavily developed land in the Town of Newbury (Buchsbaum et al 2002, DCR 2005). Monitoring in the Rowley River has shown that river is relatively clean and does not contribute significantly to the water quality impairements in the Sound (Buchsbaum et al 2002).

There is reason to believe the water quality of the Sound and its rivers may be improving. The designation of the Plum Island Sound/ Essex Bay ACEC by the State provides an extra level of political support for clean water initiatives. Additionally, the economic importance and popularity of the Sound's shellfish fishery is incentive for the surrounding communities to resolve water quality contamination problems (Brown 2001, Rickards et al 2002). The cause and scale of contamination has been established by numerous studies (i.e. Wayne and Castonguay 2000, Buchsbaum et al 2002, MCZM 2000, Brown 2001, DCR 2005). Furthermore, there are numerous water quality monitoring efforts taking place in the ACEC by state and non-profit organizations (see Section 5.4). Armed with this information, communities and the state are working to implement change (Rickards et al 2002). For example, the Town of Ipswich has made a number of upgrade to their wastewater treatment facilities (Rickards et al 2002) and the town of Newbury has developed a plan for improving stormwater runoff (DCR 2005). Additionally, the State of Massachusetts has worked to limit waste discharges from marine vessels by designating Plum Island Sound a No Discharge Zone in 2010 and providing pumpout facilities at town marinas.




Map Date: 11/20/2013 File: Listed_impaired.mxd
Data Sources: MA ILW 2010 lines and polygons, National Hydrography Dataset High Resolution flowlines and waterbodies, ESRI map service.

Figure 13. 2010 MA listed impaired waterbodies and NPDES permitted sites within or near the Parker River NWR acquisition boundary

## 5.4 Water Monitoring

WRIAs identify water-related monitoring that is taking place on, or near, wildlife refuges and fish hatcheries. For this preliminary review, the WRIA collects information stored in the USGS National Water Information System (NWIS) database. Water monitoring can be broadly categorized as either water quality or water quantity focused. Water quality monitoring typically consists of collecting surface water or groundwater samples for chemical analyses in a laboratory or with sensors deployed in the field. Alternative protocols may use techniques such as aquatic invertebrate sampling as a proxy for water quality. Water quantity monitoring typically includes the flow rate in a stream or the water level in a groundwater aquifer. WRIAs also consider weather stations and tide gages as other types of water-related monitoring.

### *5.4.1 Water Quantity Monitoring*

Multiple organizations are collecting water quantity data at 70 different sites on and near Parker River NWR (Table 9). Data for 13 of these sites can be accessed online and are listed in Table 10. The locations of the remaining 57 monitoring sites are shown in Figure 14).

The USGS conducts surface water monitoring at 10 sites upstream of the refuge acquisition boundary (Table 10, Figure 14); however, in most cases data for these sites are not available online. The closest active USGS streamflow monitoring sites on the Parker and Ipswich rivers with substantial periods of record are indicated by Map IDs 4 (Parker River at Byfield gage: 1945-present; see Section 4.4.2) and 11 (1930-present) (Table 10, Figure 14).

There are four active USGS groundwater monitoring wells in proximity to the refuge acquisition boundary, including one well at Georgetown, MA where water levels have been monitored since 1964 (Map ID 6; Table 10, Figure 14).

There are two atmospheric monitoring stations near the refuge (Map IDs 3 and 9; see Section 4.4.1) as well as a NOAA tide gage located south of the refuge (Map ID 13; Figure 14; see Section 5.4.3).

In addition to the USGS, two watershed associations on the Parker and Ipswich rivers monitor flow, depth and velocity at a total of 11 sites. The Plum Island Long-term Ecological Research (PIE-LTER) network monitors water levels in the estuary and marsh, and the refuge monitors water levels within its impoundments and in the salt marsh (Table 9, Figure 14).

Table 9. Water quantity monitoring on and near Parker River NWR. Links to online data have been provided when available.

| Agency | Parameters Measured | Record Start | How often | # of sites on refuge | # of sites near refuge |
|---|---|---|---|---|---|
| Parker River Clean Water Association (PRCWA) | Flow, depth, velocity | 1999 | Monthly from April - Nov | 0 | 7 |
| Ipswich River Watershed Association (IRWA) | Flow, depth, velocity | 1997 | Monthly | 0 | 4 |
| USGS | Groundwater, surface water | varies | varies | 0 | 10 |
| Plum Island Long-term Ecological Research (LTER) | Estuary water column transect, marsh water table, stage height | 1992 | 1992 - present | 5 | 34 |
| USFWS | Impoundment water level, salt marsh water level | | | 8 | 0 |
| NOAA | Tidal water level, atmosphere | | | 0 | 2 |

Table 10. Water quantity monitoring sites near the Parker River NWR acquisition boundary.

| # on Figure 14 | Site Number | Name | Type | Agency |
|---|---|---|---|---|
| 1 | 424841071004101 | MA-HLW 23 HAVERHILL, MA | Groundwater | USGS |
| 2 | 424520070562401 | MA-NIW 27 NEWBURY, MA | Groundwater | USGS |
| 3 | MON-PR-Met | Plum Island Ecosystems Long-Term Ecological Research Weather Station | Atmosphere | LTER |
| 4 | 1101000 | PARKER RIVER AT BYFIELD, MA | Stream | USGS |
| 5 | 424350071010201 | MA-GCW 172 GEORGETOWN, MA | Groundwater | USGS |
| 6 | 424322070592401 | MA-GCW 168 GEORGETOWN, MA | Groundwater | USGS |
| 7 | 1101100 | MILL RIVER NEAR ROWLEY, MA | Stream | USGS |
| 8 | 1101840 | PYE BROOK AT EAST BOXFORD, MA | Stream | USGS |
| 9 | 424047070495701 | IPSWICH NWS | Atmosphere | NOAA |
| 10 | 1101950 | GRAVELLY BROOK NEAR IPSWICH, MA | Stream | USGS |
| 11 | 1102000 | IPSWICH RIVER NEAR IPSWICH, MA | Stream | USGS |
| 12 | 1101740 | FISH BROOK AT LOCKWOOD LANE NEAR BOXFORD, MA | Stream | USGS |
| 13 | 8443970 | Boston, MA | Water Level | NOAA |

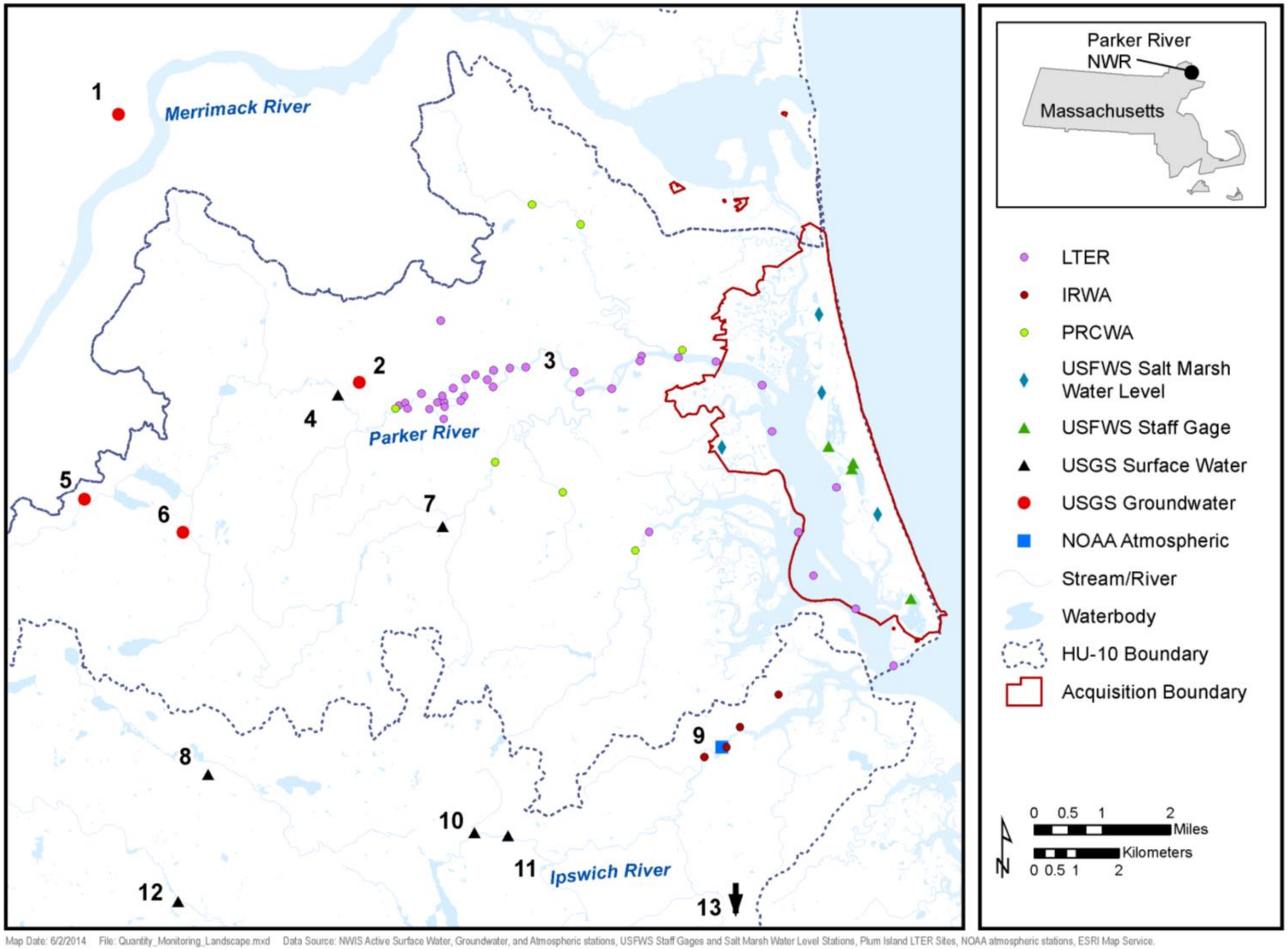



Figure 14. Water quantity monitoring near the Parker River NWR acquisition boundary.

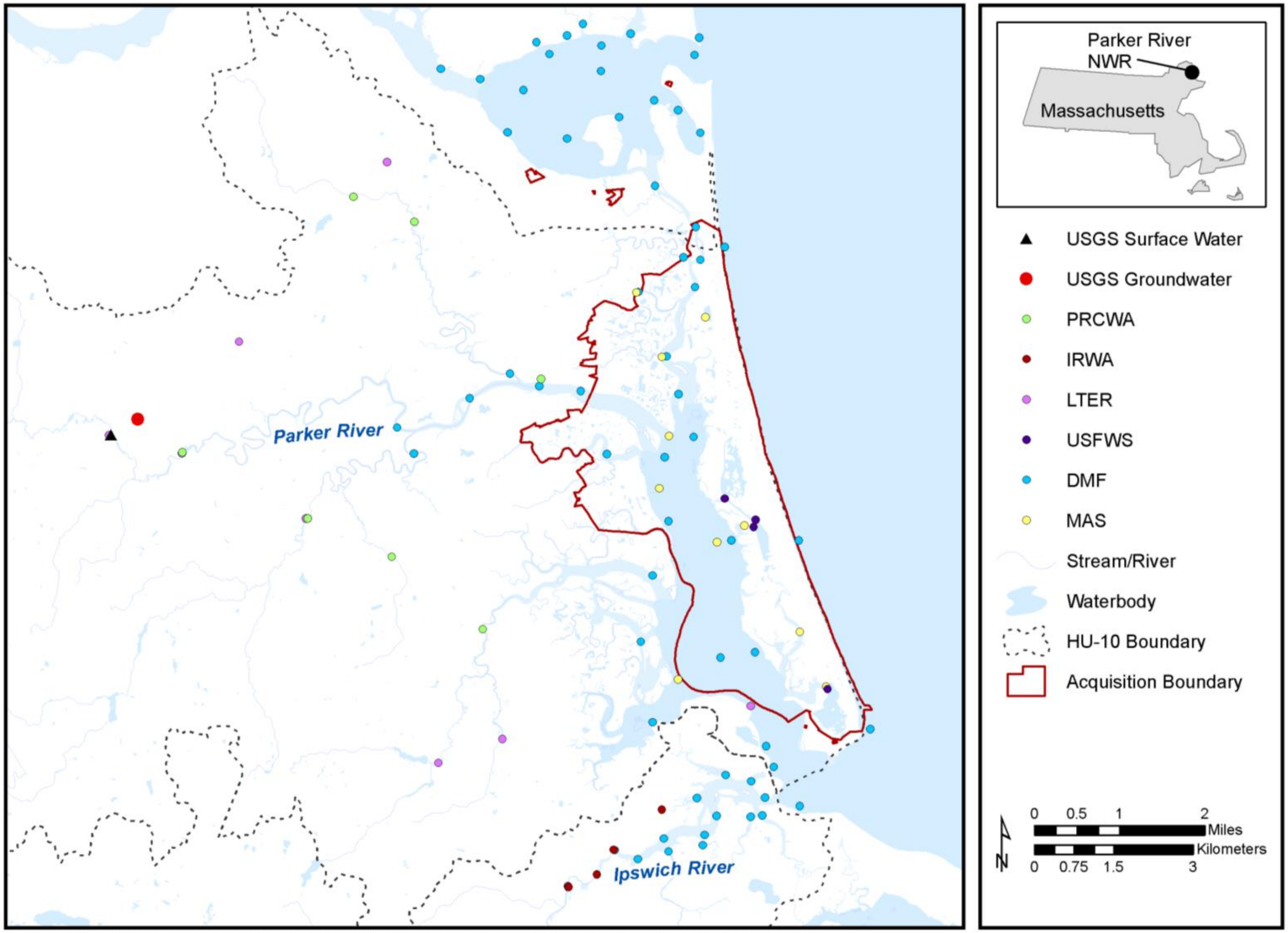
### 5.4.2 *Water Quality Monitoring*

The Massachusetts Audubon Society (MAS) and Massachusetts Division of Marine Fisheries (DMF) conduct water quality monitoring at a total of 67 surface water sites within or near the Parker River NWR acquisition boundary (Table 11, Figure 15). Additionally, PRCWA and IRWA collect monthly water quality samples at various locations within the Plum Island Sound-Frontal Atlantic and Ipswich watersheds. Refuge staff collect salinity data at each of the four water control structures. The site with the longest period of record for water quality sampling is the USGS gage on the Parker River at Byfield (Table 11, Figure 15).

Groundwater quality information in the area around the refuge is relatively scarce. Water quality data from one site visit were collected at USGS well MA-NIW in Newbury near the Parker River (Site number 424520070562401) in 1960.

Table 11. Surface water quality monitoring within or near the Parker River NWR acquisition boundary

| Agency | Parameters Measured | Record Start | How often | # of sites on refuge | # of sites near refuge |
|---|---|---|---|---|---|
| Parker River Clean Water Association (PRCWA) | Fecal coliform, DO, pH, Temp, NO3-N, TP | 1999 | Monthly from April - Nov | 0 | 7 |
| Ipswich River Watershed Association (IRWA) | Fecal coliform, DO, pH, Nutrients, Temp, Color, Odor | 1997 | Monthly | 0 | 4 |
| USGS | Surface water temperature, specific conductance, DO, pH, NO3-N, TP, suspended sediment | 1971 | 1971-2003 | 0 | 2 |
| Long-term (LTER) | Nutrients, Temp | 1992 | 1992-present | 0 | 12 |
| USFWS | Salinity | | | 4 | 0 |
| Division of Marine Fisheries (DMF) | Fecal coliform, Temp, Salinity | 1985 | Continuous | 13 | 45 |
| Massachusetts Audubon Society (MAS) | Fecal coliform, Temp, Salinity | 1992 | 1992-1995 | 8 | 1 |




Map Date: 6/2/2014 File: Quantity_Monitoring_Landscape.mxd Data Source: NWIS Active Surface Water, Groundwater, and Atmospheric stations, WQMSTAT monitoring stations, ESRI Map Service.

Figure 15. Water quality monitoring within or near the Parker River NWR acquisition boundary.

### *5.4.3 Long-Term Tidal Monitoring*

The closest long-term tide gage to Parker River NWR is in Boston, MA (Station 8443970) (Map ID 13, Table 10, Figure 14). At one time a tide gage was located at Plum Island near the Merrimack River entrance (Station 8440452). However, that gage was removed in 1989. Mean tidal range is 9.49 feet at Boston, with diurnal ranges of 9.40 and 10.27 feet, respectively (Figure 16). The estimated mean sea level difference between sampling periods of 1960-1978 and 1983-2001 at the Boston station is 0.13 feet. The mean tidal range from the discontinued station at the Merrimack River entrance was 8.86 ft (Clough and Larsen 2012).

Seasonal changes in local sea level measured at the Boston tide gage indicate water levels at the station tend to be at their highest between May and November, and lowest between December and March (Figure 16). The difference between the mean monthly maximum and minimum sea level in Figure 16 is approximately 0.07 meters (2.75 inches). Seasonal changes are a function of dominant weather patterns that drive water into or out of Massachusetts Bay. These seasonal weather patterns result in changing ocean currents, increased runoff, and thermal expansion of water.

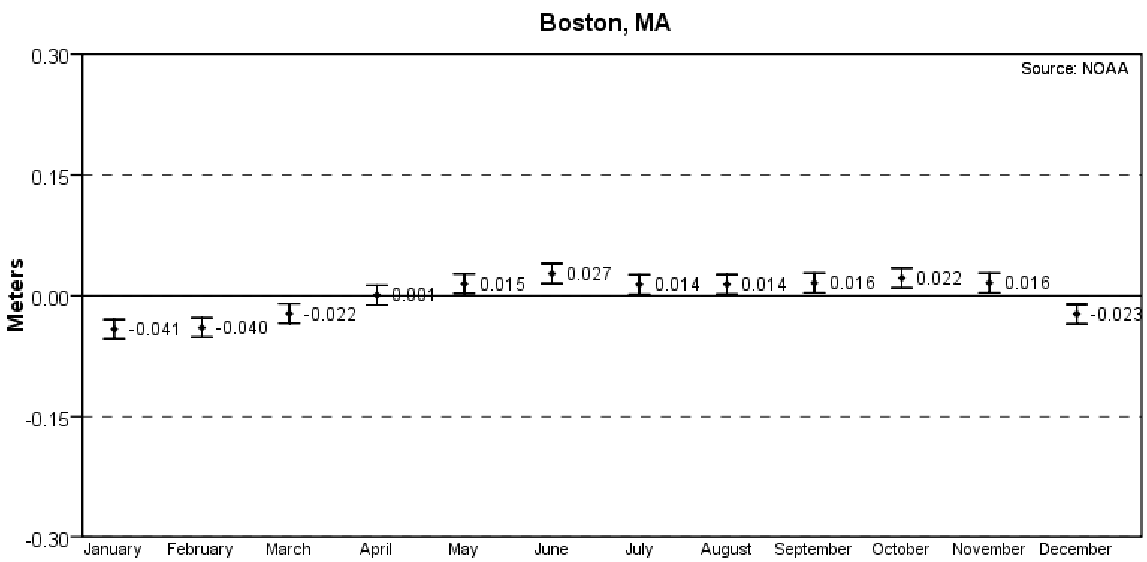



Figure 16. Average monthly variation in mean sea level due to temperature, ocean currents, and weather patterns. Graph is from the station's website (link).

### *5.4.4 Water Monitoring Data Gaps*

Parker River NWR is fortunate to have numerous partner organizations and interested parties operating water quantity and quality monitoring programs in Plum Island Sound and its associated watersheds. At the refuge-scale, the existing water monitoring at refuge impoundments and at select salt marsh sites seems adequate for tracking management activities. Exceptions are monitoring water levels in the freshwater lens that supports interdunal swale wetlands and long-term tidal monitoring in Plum Island Sound.

At the watershed-scale, the level of monitoring appears to be adequate to address the water quantity and water quality issues that have been identified by earlier studies (MCZM 2000, Gomez and Sullivan 2003, Horsley and Witten Group 2008, IRWA 2012). However, data gaps exist in space and time. Monitoring tends to be concentrated on the Parker and Ipswich Rivers or in the Sound with fewer measurements being made on smaller tributaries like the Little River in Newbury. The frequency of monitoring varies depending on available resources of the organization making the measurements and the purpose of the monitoring. Long-term monitoring efforts tend to make measurements monthly or less frequently. In addition to gaps in distribution and timing, it appears there are few sites where samples are being collected to quantify concentrations of heavy metals and other environmental contaminants such as mercury.

## 5.5 Water Rights

Parker River NWR does not withdraw water from surface water or groundwater sources for refuge purposes and therefore does not require state-issued water use permits. However, each WRIA includes a summary of the water laws in the state where the refuge is located. Water Law in Massachusetts was recently summarized by the DOI's solicitor's office. The document provides an in-depth review of the legal framework governing water use in Massachusetts. The summary of Massachusetts water law in the Solicitor's memo is included below:

*Persons withdrawing water from any water source in excess of 100,000 gallons per day or nine (9) million gallons in any 3-month period must obtain either a permit or a registration statement from the Massachusetts Department of Environmental Protection ("DEP") under the Massachusetts Water Management Act. A permit is required for new water withdrawals. A registration statement filed before January 1, 1988 is required to grandfather existing water withdrawals. A permit amendment is required for any changes to an existing permit.*

*Water withdrawals that do not exceed the Water Management Act threshold volume are governed under traditional Massachusetts common law unless an applicant voluntarily files for a permit under the Act. Groundwater withdrawals are controlled under the absolute ownership doctrine, meaning an owner may withdraw groundwater, without limitation, even if it causes injury to their neighbor. Surface water withdrawals are governed under the reasonable use doctrine, meaning a riparian owner may make reasonable use of the water provided that the use does not interfere with the mutual rights of other riparian owners.*

*Persons (including officers of public agencies) must obtain a discharge permit before discharging pollutants into waters of the Commonwealth. Permits issued may either be NPDES non-industrial surface water permits subject to state surface water permit regulations or ground water permits. "Concentrated aquatic animal production facilities" that discharge water must obtain a permit before discharging pollutants into surface waters.*

*In the event of an existing or impending water shortage, the Massachusetts Water Management Act also gives the Department of Environmental Protection the authority to declare a "state of water emergency" and to establish a mechanism to prioritize water distribution among competing uses. In addition, Massachusetts has several viable ways to address the possibility of water shortages before and after the permitting process. There is also a mechanism for the U.S. Fish and Wildlife Service to challenge other permits, withdrawals, and DEP decisions.*

*While federal agencies are generally exempt from state regulatory programs unless there is an express waiver of sovereign immunity, the National Wildlife Refuge Administration Act has expressly waived sovereign immunity for the FWS and thus it must comply with state water rights allocation programs.*

### *5.5.1 Sustainable Water Management Initiative (SWMI)*

Massachusetts's Sustainable Water Management Initiative (SWMI) was initiated in 2010 to develop an approach for the "sustainable management of water resources that balance human and ecological needs" (EEA 2012). The goal of the SWMI effort is to quantify the volume of water available for human use in Massachusetts' watersheds while still leaving enough water in rivers and streams to support aquatic habitat and the species that depend on it. The SWMI effort relied heavily on a USGS study (Armstrong et al 2010) and scientific review by a technical committee of scientists from State, Federal, and Academic institutions. SWMI defines three new criteria that will be incorporated into water use permitting decisions under the Massachusetts Water Management Act (EEA 2012).

- ***Safe Yield*:** The maximum amount of water that can be withdrawn from major watersheds.

- ***Seasonal Streamflow Criteria***: The amount of streamflow alteration that can occur from groundwater withdrawals. One objective of establishing these seasonal criteria is to ensure rivers' seasonal runoff patterns continue. Therefore, the amount of allowable alterations varies seasonally. However, particular focus is given to the summer months (July, August, September) because this is when water demand is greatest and aquatic species are most sensitive to low flow conditions.

- ***Baseline***: Is the amount of water that can be withdrawn by a water user or Public Water Supply. New water use applications or increases in water use will be compared to the "baseline" to determine if they increase the volume of water withdrawn. DEP will define baseline from the user's water use records between 2003-2005.

The SWMI framework (EEA 2012) proposes changes to the regulation of the Massachusetts Water Management Act. As of 2014, the proposed changes have not been officially adopted by the state. Once adopted, the new regulations will institutionalize protections for aquatic habitat into the state's water use regulations.

## 5.6 Climate Trends

A variety of datasets exist that can be used to evaluate long-term climate trends at refuges in Region 5. Some of these data are included in the WRIA to provide a preliminary analysis of trends in precipitation, temperature and stream runoff. Data were analyzed for trends using the nonparametric Mann-Kendall statistical test. This test can be used to determine if there is a linear trend in a dataset and whether or not that trend is statistically significant ($p < 0.05$) (Helsel and Hirsch 2002).

### *5.6.1 U.S. Historical Climatology Network (USHCN)*

The USHCN is a network of climate monitoring sites maintained by the National Weather Service. Sites in the network are selected because their location and data quality make them well suited for evaluating long-term trends in regional climate. The closest site to the refuge is located in Lawrence, MA. Data from the site illustrates trends in precipitation and air temperature in the Parker River watershed over the last 115 years (Figures 17-19) (Menne et al 2011).

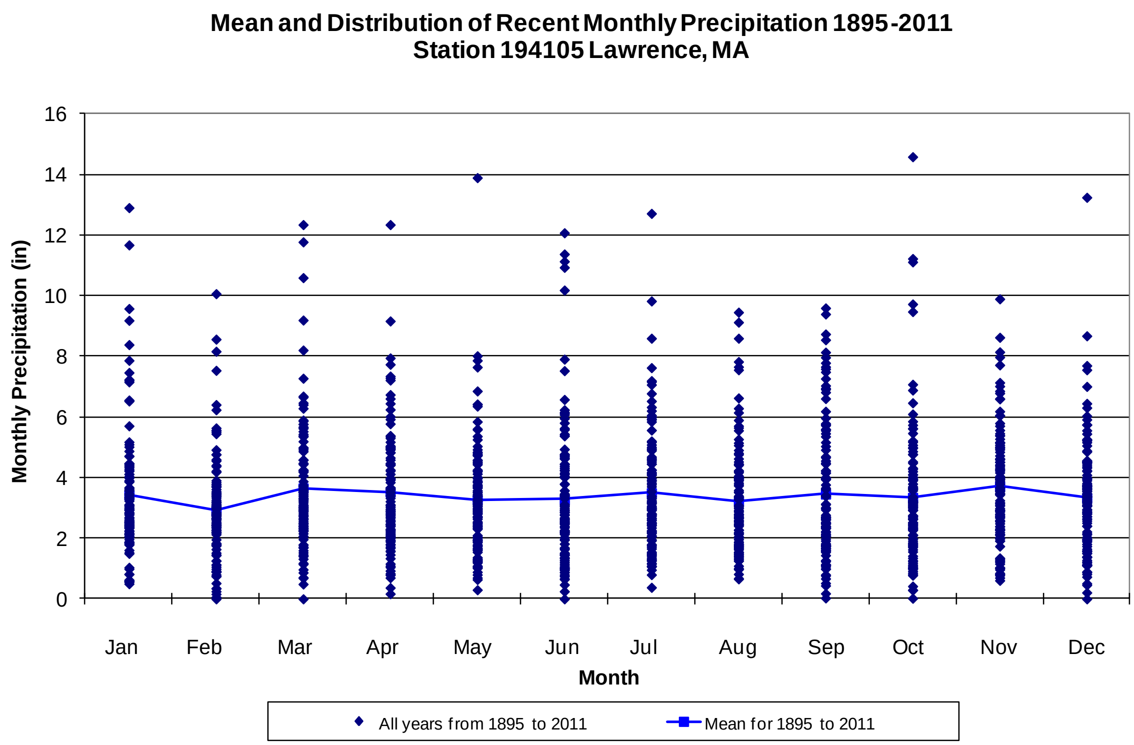
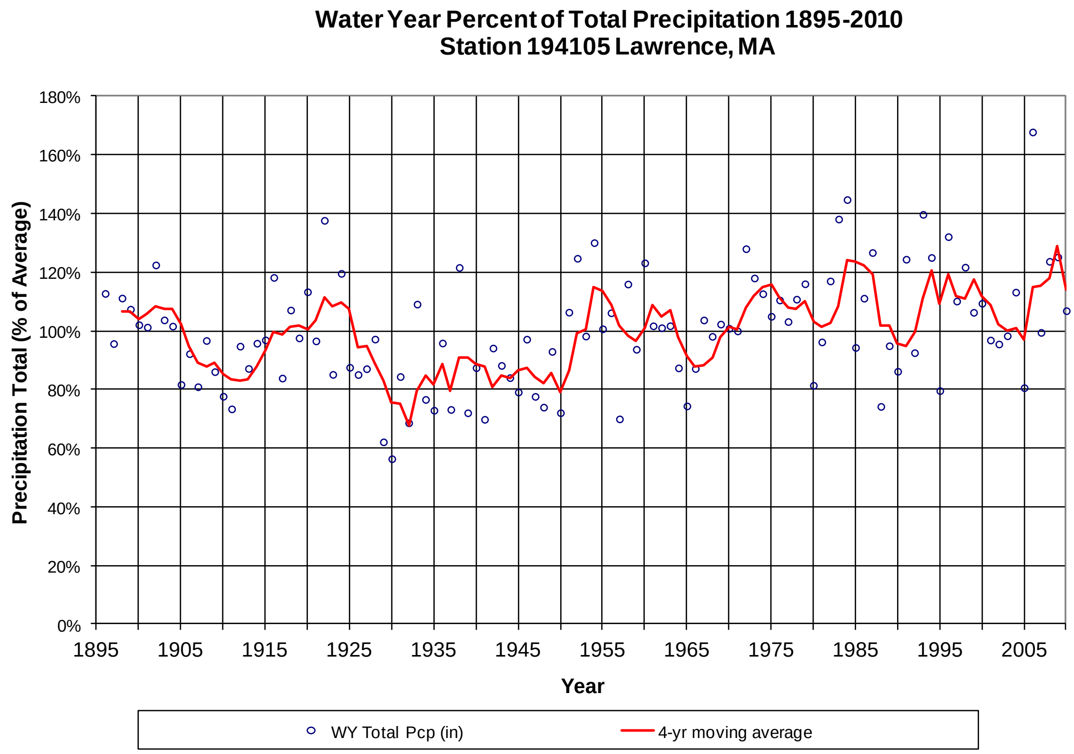



Figure 17. Mean and distribution of total monthly precipitation at USHCN Station 194105 in Lawrence, MA: 1895-2011.

Trends presented in Figure 17:

- Precipitation falls in a fairly uniform distribution throughout the year.
- Average monthly precipitation is 3.5 inches.
- Average water year total precipitation is 40.7 inches.

Precipitation patterns were evaluated by calculating the difference between each year's average precipitation and the average for all years. Presented as a percent, this approach can be used to identify years of above average, or below average, precipitation (Figure 18).




**Note: "Water Year" runs from October 1 through September 31. It is commonly used to track hydrologic data.**

Figure 18. Percent of total Water Year precipitation at the Lawrence, MA USHCN site between 1895 and 2010.

Trends presented in Figure 18:

- The 1965 drought that affected many areas of the U.S. Northeast (Seager et al 2012) shows up clearly in the record. However, the 1930s and 1940s appear to be a more severe and prolonged drought period (USGS 1989) in this portion of New England.

- Precipitation totals have regularly been above average since the 1960s which agrees with observations at other weather stations in the U.S. Northeast (Seager et al 2012).

- Water year precipitation totals have increased approximately 8.0 inches over the period of record (1896-2010). The increasing trend is statistically significant ($p < 0.05$) using the nonparametric Mann-Kendall test.

Monthly temperatures at the Lawrence, MA USHCN site were also reviewed to identify any patterns in air temperature since 1895 (Figure 19). There is a noticeable trend of increasing air temperatures over the period of record.

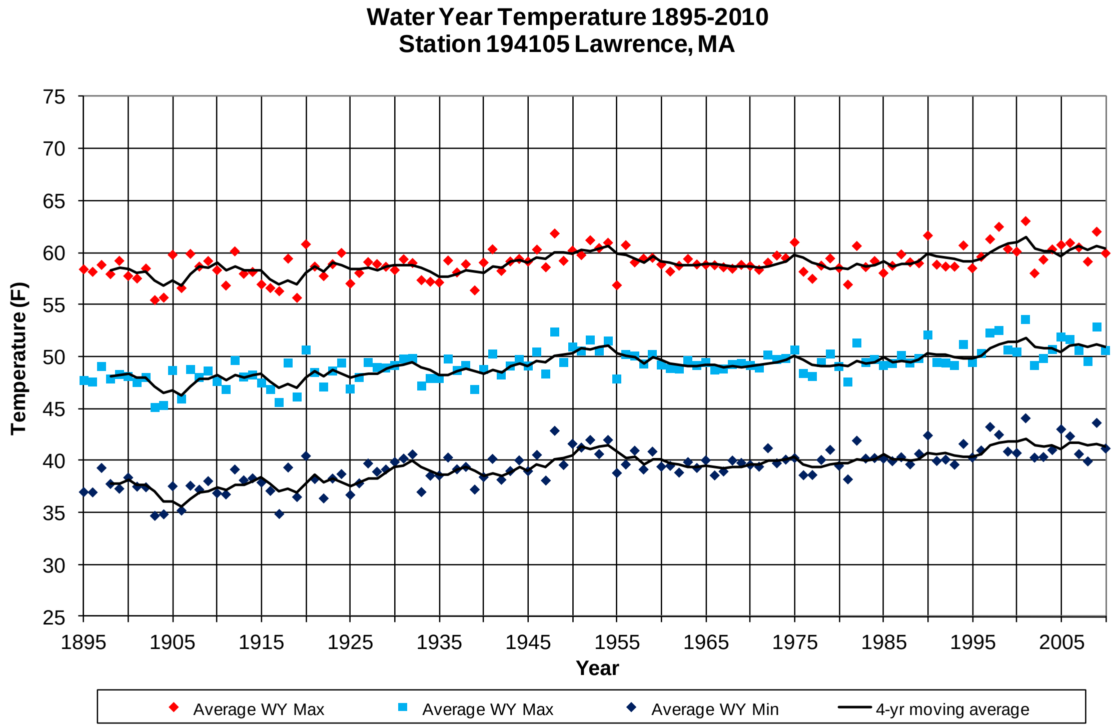



Figure 19. Average temperatures for the Water Year: 1895-2010 at the USHCN station in Lawrence, MA. The Water Year extends from 10/1 – 9/30 of a year.

Trends presented in Figure 19:

- Average water year maximum temperature has increased approximately 2.7 F over the period of record (1895-2010). This is a statistically significant trend.
- Average water year mean temperature has increased approximately 3.0 F over the period of record (1895-2010). This is a statistically significant trend.
- Average water year minimum temperature has increased approximately 3.4 F over the period of record (1895-2010). This is a statistically significant trend.

Maximum, mean, and minimum water year temperatures measured at the Lawrence, MA USHCN station have all increased significantly since 1895. These increases agree with studies showing global temperatures are rising (Bates et al 2008) and regional studies showing increasing air temperatures in the northeastern U.S. (Hayhoe et al 2007).

### *5.6.2 USGS Hydro-Climate Data Network (HCDN)*

The HCDN is a network of USGS stream gaging stations that are considered well suited for evaluating trends in stream flow conditions (Slack et al 1992). Sites in the network have periods of record that exceed 20 years and are located in watersheds that are relatively undisturbed by surface water diversions, urban development, or dams.

The Parker River at Byfield, MA USGS gage is not in the HCDN network; however, it is the closest gage with a substantial period of record. Flow patterns in the Parker River were evaluated by calculating the difference between each year's average discharge and the average for all years. Presented as a percent, this approach can be used to identify years of above average, or below average, runoff (Figure 20).

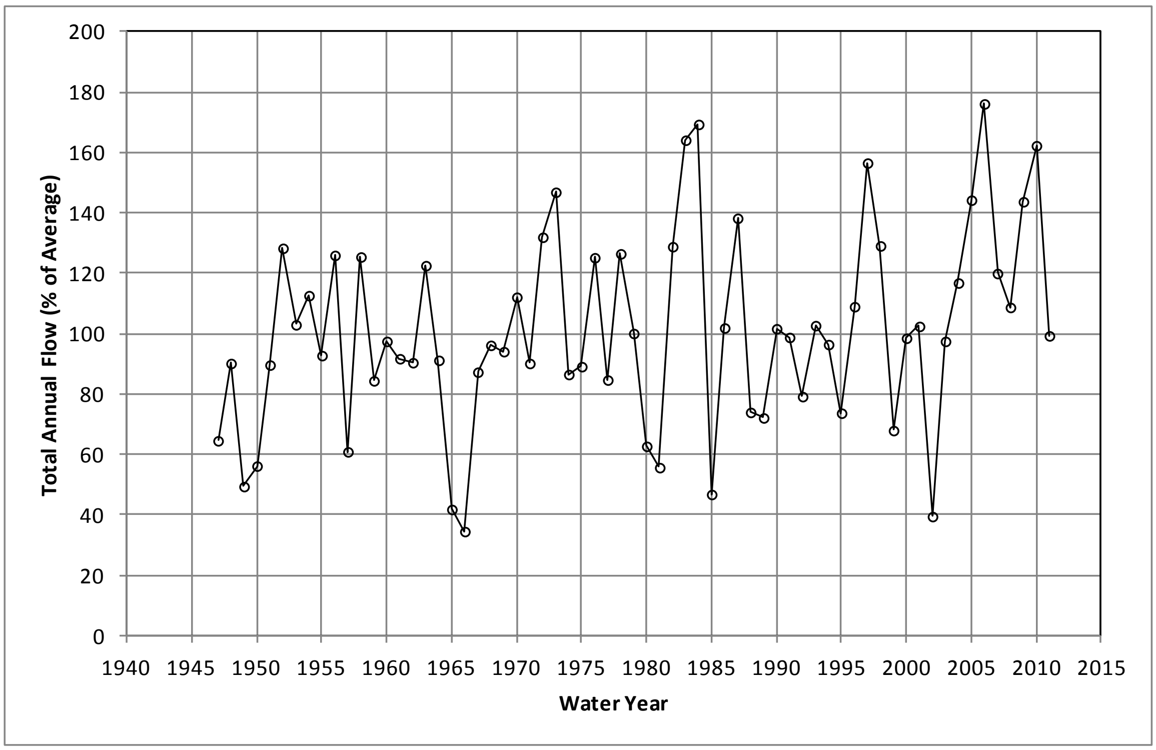



Figure 20. Percent of the average annual flow on the Parker River at Byfield, MA: 1947-2011.

Trends presented in Figure 20:

- The 1960s drought dramatically affected flow in the Parker River and remains the most pronounced period of below average flow for the period of record.
- 2002 and the late 1940s were also particularly dry years when mean annual flow approached 40% of the period of record average.

- The average annual flow from the period of record is 38.6 cfs.
- The highest average annual flow was in 2006 (67.4 cfs).
- The lowest average annual flow was in 1966 (13.2 cfs), when streamflows in the eastern part of the state reached their lowest (USGS 1989). The average flow in 2002 was 15.1 cfs, the second lowest average annual flow over the period of record.
- Average annual flows on the Parker River were above average between 2003 and 2011.

The long-term record presented in Figure 20 is expected to reflect conditions in other streams flowing into Plum Island Sound. Streamflow patterns in Parker River at Byfield roughly correspond to total precipitation data presented in Figure 18. The strong response to drought conditions in the 1960s is similar to the response observed in many watersheds throughout the Northeast. This drought is considered the “drought of record” for the northeastern U.S. (Hayhoe et al 2007, Seager et al 2012).

Data from the USGS gage on the Parker River at Byfield, MA is affected by water diversions upstream of the gage. Over the past two decades, the Parker River has experienced flow conditions significantly lower than historic averages. Over the period of record, the 7-day annual minimum flow is 0.48 cfs, but from 1993 to 2003 the 7-day average minimum flow ranged from 0.04 cfs to 0.16 cfs, even lower than during the 1960s drought (Gomez and Sullivan 2003).

### *5.6.3 Future Climate Predictions*

The Intergovernmental Panel on Climate Change (IPCC) predicts the U.S. Northeast will experience earlier spring snowmelt and reduced summer runoff as the global climate warms in response to human emissions of greenhouse gasses (Bates et al 2008, Mack 2008). Hayhoe et al (2007) review historic climate data and climate change models to evaluate the Northeast’s response to global climate change. Results of their analyses are summarized below:

#### *Temperature*

Air temperature records in the Northeast show consistent signs of warming since the 1970s with the greatest increases occurring during the winter months. Warming trends are expected to continue and rates of warming increase under different climate modeling scenarios. As temperatures warm the frequency of extreme warm temperatures will increase also.

### *Precipitation*

Precipitation records in the US Northeast show a consistent increase in annual precipitation totals over the last century. Under different climate modeling scenarios, winter precipitation is expected to increase while summer precipitation is expected to remain unchanged or decrease. Heavy, intense precipitation events are expected to become more common also.

### *Snowpack*

The amount of snow cover has decreased across the Northeast in the last 30 years. This trend is expected to continue with less precipitation falling as snow in the winter months.

### *Streamflow Patterns*

Since 1970, peak snowmelt runoff has occurred earlier in the year and the peak runoff values have been rising in winter and early spring. These patterns are expected to continue as wetter winters and warmer temperatures decrease winter snowpacks. The response to seasonal snowmelt will become less pronounced as more winter precipitation falls as rain. Peak flows are expected to be concentrated in the winter and early spring months and minimum streamflow will continue to be concentrated in the summer months. Minimum flows will be lower than the recent past and the duration of the summer low flow period is expected to increase.

### *Drought*

Modeling scenarios predict that the frequency of severe, persistent drought (> 6 months) will remain at rates observed in the recent past. However, hotter drier summers and periodic precipitation deficits are expected to increase the frequency of short- (1-3 month) and medium-term (3-6 month) droughts. Periods of drought will be most pronounced at the end of the growing season in the late summer and early fall.

## *5.6.4 Sea Level Trends*

Predictions included in the Intergovernmental Panel on Climate Change (IPCC) report put the range of global sea level rise between 0.75 and 1.90 meters (2.46 - 6.23 feet) by 2100 (Horton and Miller 2010). Data from the Boston tide gage suggests the local sea level is rising about 2.63 millimeters (0.1 inches) per year (Figure 21), higher than the average global rate of 1.8 mm/yr (Horton and Miller 2010). Sea level at the Boston gage is rising faster than the global average because the land surface at the gage is subsiding, or sinking. The estimated vertical land movement from subsidence and sediment compaction at the Boston gage is -0.84 mm/year (MCZM 2013).

The Sea Level Affecting Marshes Model (SLAMM) attempts to quantify changes to coastal wetland habitat due to sea level rise using data from NOAA tide gages, USFWS National Wetland Inventory maps, and USGS digital elevation models. For Parker River NWR, SLAMM was used to predict wetland community changes by 2100 to four sea level rise scenarios: 0.39 m, 0.69 m, 1.0 m and 1.5 m (1.3 - 6.6 feet) (Clough and Larsen 2012). The SLAMM simulation of Parker River NWR indicates a refuge vulnerable to the effects of sea level rise. The model predicts that 52% to 100% of irregularly flooded (brackish) marsh, which makes up more than one-third of the refuge, will be lost (converted to tidal flat and open water) under the 0.69 to 1 m sea level rise scenarios. The refuge is predicted to lose between 16% and 46% of its undeveloped dry land, across all scenarios (Clough and Larson 2012).

For the changes presented in the SLAMM analysis to occur, the current rate of sea level rise needs to increase considerably. At the current rate of 2.63 mm/year, Parker River NWR would not experience sea levels equivalent to any of the prediction scenarios by the year 2100; the 0.39 m scenario would be achieved in the year 2162; and the 1.5 m scenario would be achieved in the year 2584.

Tide gages record a local measurement of sea level relative to a fixed point on land near the gage site. The amount of local sea level rise and the impacts on estuaries at Parker River NWR will depend on many factors including the morphology of the coast line and human modifications to the coast like tide gates and levees (Horton and Miller 2010). Many studies have shown that marsh accretion rates can keep pace with sea level rise where there is adequate sediment supply (Kirwan et al 2010). Sediment Elevation Table (SETs) data from two Parker River NWR salt marshes show they are keeping pace with the current rate of sea level rise of (USFWS 2012). However, the capacity of the marsh to keep pace with sea level rise may be limited if the rate of rise increases (Glick 2012). Modelling by Kirwan et al (2010) suggest a threshold rate for Plum Island Sound salt marshes is 5 mm/yr. Once sea level rise reaches this rate, modelling suggests conversion of salt marsh habitat to unvegetated, subtidal environments takes approximately 30 – 40 years (Kirwan et al 2010). However, observations at Parker River suggest this transition can occur much more rapidly, on a scale of 5-7 years (Nancy Pau, personal communication).

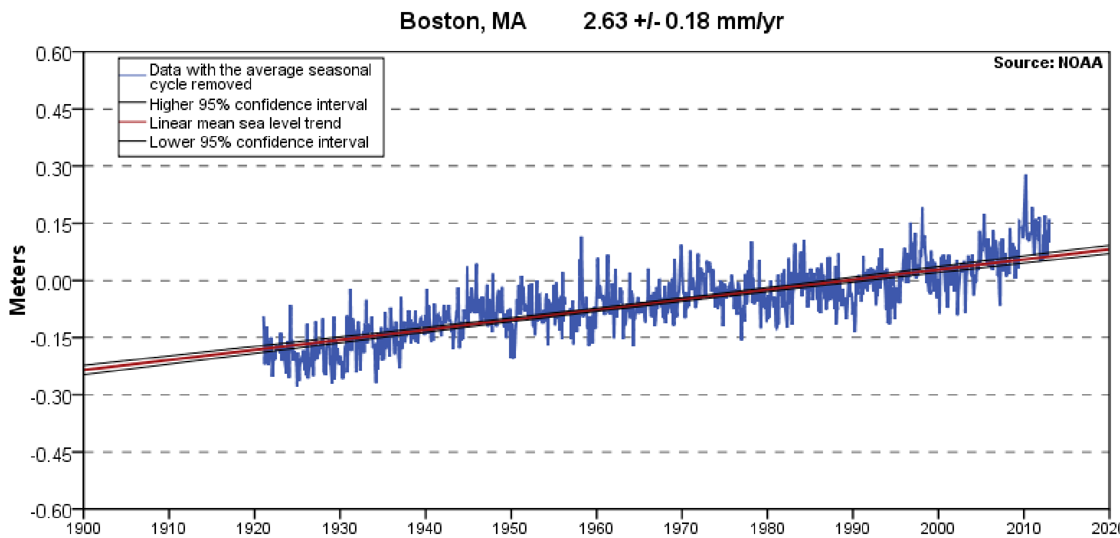



Figure 21. Mean sea level trend at NOAA station 8443970 in Boston, MA. The mean sea level trend is 2.63 millimeters/year with a 95% confidence interval of +/-0.18 mm/yr based on monthly mean sea level data from 1921 to 2006, which is equivalent to a change of 0.86 feet in 100 years.

### *5.6.5 Climate Change Implications for Parker River NWR*

The climate trends discussed in Section 5.6 mirror the trends observed throughout the Northeast (Hayhoe et al 2007). At Parker River, management challenges that will be exacerbated by a warming climate include increased flooding and saltwater intrusion from sea level rise and storm events, as well as changing precipitation patters, particularly increased short-term droughts.

As indicated by the SLAMM analysis, refuge habitats are vulnerable to effects associated with increased rates of sea level rise. (e.g., marsh converted to tidal flat) (Clough and Larsen 2012). The high marsh, which is dominated by *Spartina patens*, is the most vulnerable as *S. alterniflora* invades from lower elevations and *Phragmites australis* invades from higher elevations (Buchsbaum undated). The refuge's buffer zone may allow some inland marsh migration; however, it will be limited by nearby suburban development and sediment supply (Glick 2012). On the eastern edge of Plum Island Sound salt marshes, landward migration is blocked by the impoundment dikes and the refuge access road (Nancy Pau, personal communication). Coastal habitats are also at risk from stochastic events, such as coastal storms, the intensity of which is correlated with increasing ocean temperatures. Tebaldi et al (2012) estimated that the frequency of 100-year storm events is predicted to increase in Boston by 2050.

The barrier island-like groundwater system that supports the interdunal swales on Plum Island is also vulnerable to sea level rise. Even a conservative scenario of a 20 cm sea level increase, can decrease the depth to the water table and thin the freshwater lens (Masterson et al 2013). These changes affect wetland plant distribution by increasing the frequency of inundation in interdunal swales and facilitating salt-water intrusion on the wetland margins of the barrier island.

Other freshwater impacts include increased flooding from intense rain events and short-term droughts as summers become hotter and drier. Drier conditions have particular implications for freshwater flow conditions in the Parker and Ipswich Rivers, which already experience extreme low flows during dry summers. Low flow conditions are exacerbated by residential water use, which is often greatest during dry summers (Zariello and Ries 2010). More frequent and intense rainfall, generates stormwater runoff that transports waste and contaminants into the waters of Plum Island Sound. Changes in precipitation may affect management of water levels in the impoundments, which depend on precipitation and water from the Plum Island Sound for their water supply. Because of their proximity to the shoreline and low elevation, the impoundments are likely to be some of the first areas affected by sea level rise and coastal storms (Glick 2012).

# 6 ASSESSMENT

## 6.1 Water Resource Issues of Concern

This section discusses some of the challenges the refuge's water resources face. For the purposes of this initial review the primary water resources of interest are the wetland systems that are within the acquisition boundary of the refuge.

### *6.1.1 Sea Level Rise*

The SLAMM report (2012) predicts how Parker River NWR wetlands will change in response to sea level rise. Although the refuge salt marshes appear to be keeping pace with the current rates of Sea Level Rise future rates may eventually overwhelm the marsh (Kirwan et al 2010). The refuge can expect a shift in salt marsh habitat landward and will need to use that knowledge to prioritize future land acquisitions or management activities. In addition to changes in the salt marshes, sea level rise is expected to strengthen the hydrologic connection between the Merrimack River Estuary and the Plum Island Sound. This has implications for freshwater/salt water exchange in the northern third of the Sound and potentially facilitates contaminant transport from the Merrimack to the Plum Island Sound. Masterson's (2013) work suggests the freshwater lens in the Plum Island dunes may be very sensitive to rising sea levels which could lead to wetter conditions in interdunal swales. Existing changes in sea level are probably already manifesting as habitat change near the saltwater / freshwater marsh interface.

### *6.1.2 Water Quality of Plum Island Sound*

Due to rapid tidal flushing, water quality in Plum Island Sound is generally good (Buchsbaum et al 2002). However, the upper reaches of the estuary, in the tidal portions of the river channels, are most sensitive to water quality impairments during periods of low freshwater flow (Vallino and Hopkinson 1998). Suburban development in the watersheds contributing to the sound has led to impairments due to excess human and animal waste. Impairments are particularly acute following rain events due to stormwater runoff. Shellfish resources, in particular, are negatively impacted by this type of contamination but other wildlife species that rely on aquatic habitat in the Sound are sensitive to contamination too. The potential for improving water quality in Plum Island Sound is high because numerous studies and inventories have identified the specific causes of impairment in the watershed. In general, there appears to be widespread political support for improving the Sound's water quality. Local communities and non-governmental organizations have been proactive about finding resources to ensure infrastructure and regulatory changes are made that improve water quality.

## 6.2 Needs and Recommendations

More than 75% of the Parker River NWR acquisition boundary is estuarine marsh and deepwater habitat. The loss of this habitat due to sea level rise is, of course, the most obvious long-term threat to the refuge. The primary threats to water resources at Parker

River National Wildlife Refuge are associated with sea level rise and water quality conditions in Plum Island Sound.

### *6.2.1 Water Level Monitoring near Interdunal Swales*

The refuge is already monitoring water levels and surface elevations in Plum Island Sound salt marshes. These efforts should continue and can build a long-term record that tracks changes to refuge habitat due to sea level rise. However, it appears less emphasis has been placed on monitoring water level conditions in the freshwater lens that supports Plum Island's interdunal swales. Although these wetlands are a small percentage of the total wetland acreage on the refuge, they are ecologically important freshwater wetland communities. Recent studies (Masterson et al 2013) suggest freshwater lens aquifers in barrier islands can be particularly sensitive to sea level rise. The refuge should consider adding one or two shallow groundwater wells with continuous water level recorders in the dune field adjacent to interdunal swales. These data will complement other water level monitoring in refuge salt marshes and build a long-term dataset that quantifies the impacts of sea level rise on refuge freshwater resources.

### *6.2.2 Continue to support watershed restoration and salt marsh restoration efforts*

Parker River NWR is fortunate to be located in a watershed with multiple partner organizations who are dedicated to improving the overall quality of the Sound and the rivers that flow into it. Recent observations of increased inundation of high marsh and the associated conversion of high marsh to low marsh habitat, suggests salt marsh loss due to sea level rise is already occurring. As a major land owner of salt marsh in Plum Island Sound, the refuge is well situated to pilot new techniques for restoring natural hydrologic conditions to improve the resiliency of the Sound's salt marshes

Recommend the refuge continue to support restoration projects that mitigate the impacts of grid ditching and tidal flow restrictions in Plum Island Sound salt marshes. In addition, recommend the refuge continue supporting efforts to reduce stormwater runoff and improve water quality in the rivers flowing into the Sound. The Parker River watershed is particularly important because water quality conditions in this river have the most impact on the portion of the Sound within the refuge boundary. Restoration activities that reduce stormwater runoff and restore rivers' natural flow regimes can benefit the Sound by reducing water quality impairments, increasing summertime freshwater inputs, and increasing the sediment supply to the Sound.

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